GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. A-3532 GTRI/GIT DATE 5/19/83

Project Director: Joe Newton School/Lab EML

Sponsor: US Army Missile Command; Redstone Arsenal, AL 35898

Type Agreement: Delivery Order No. 0010 under Contract DAAH01-83-D-A013

Award Period: From 5/5/83 To 9/30/83 (Performance) 11/30/83 (Reports)

Sponsor Amount:	This Change	Total to Date
Estimated:	$ 48,850	$ 48,850
Funded:	$ 48,850	$ 48,850

Cost Sharing Amount: $ None Cost Sharing No:

Title: IRAG Hardware Development Task Order RDF-13.

ADMINISTRATIVE DATA

OCA Contact Frank H. Huff x4820

1) Sponsor Technical Contact:

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Systems Simulation & Dev. Directorate
US Army Missile Command
US Army Missile Laboratory
ATTN; DRSMI-RDF
Redstone Arsenal, AL 35898

2) Sponsor Admin/Contractual Matters:

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Georgia Institute of Technology
Atlanta, Georgia 30332

Defense Priority Rating: DO-A2 under DMS Reg 1

Military Security Classification: Unclassified (general scope of work)
(or) Company/Industrial Proprietary:

RESTRICTIONS

See Attached Gov't Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category. See additional restrictions on re-budgeting travel funds: (2) C-2(f) (page 4 of basic agreement) (1) B-2(c) (page 3 of basic agreement)

Equipment: Title vests with Government; except that items costing less than $1,000 vest with GIT if prior approval to purchase is obtained from the Contracting Officer.

COMMENTS:

Send information copy of all correspondence addressed to Administrative Contracting Officer (ACO) to Commander, US Army Missile Command, Attn: DRSMI-ICDB, Redstone Arsenal, AL 35898

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FORM OCA 4:383

ORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF CONTRACT ADMINISTRATION

2-N-SR14

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 11/8/83

oject No. A-3532

~~School~~/Lab EML

cludes Subproject No.(s) N/A

oject Director(s) Joe Newton GTRI / ~~XXXX~~

onsor U.S. Army Missile Command; Redstone Arsenal

itle IRAG Hardware Development Task Order RDF-13.

Effective Completion Date: 9/30/83 (Performance) 11/30/83 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [X] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [X] Final Report of Inventions
- [X] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Continues Project No. ______ Continued by Project No. ______

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A-3532

MONTHLY TECHNICAL REPORT #1

IRAG Hardware Development
Georgia Tech Project A-3532

Joe M. Newton
Michael Leon

Report Period
5 May through 31 May 1983

Contract #DAAH01-83-D-A013
Delivery Order #10

Effective Date: 5 May 1983
Expiration Date: 30 September 1983

Prepared for

U. S. Army Missile Command
Advanced Sensors Directorate
Redstone Arsenal, Alabama 35898

Prepared by

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

WORK PERFORMED IN THIS WORK PERIOD

1.0 Mechanical Design

During this work period most of the design work needed to implement the IRAG configuration has been completed. The RF antenna has been modified to accommodate the passage of the four Kelvar strings from the IR assembly to the take-up reel, located behind the RF antenna. This was done by drilling and then counter-drilling four holes through the antenna as shown in drawing #024. In addition, it has been found necessary to insert ruby bearings into these holes to prevent the strings from being chafed. The bearings are placed into the front of the antenna via bearing cups as shown in drawing #025. The cups are held in place by glue.

The design for the IR seeker assembly and the string adjusters have also been completed. The string adjuster design is shown in drawings #22 and #23. Each string adjuster has a pulley which routes the strings from the hole in the RF antenna to the take-up reel. The adjusters are equipped with an adjustment mechanism as shown in drawing #016. These adjustments allow the lengths of the pulley strings to be equalized.

2.0 Electrical Tests

Most of the electrical tests have been completed. The modification process has been electrically followed through the several stages. These are: (1) Radome boresight measurement with original antenna and radome. (2) radome boresight measurements with modified radome and original radome, (3) radome boresight measurements with modified antenna and IR dome, (3) radome boresight measurements with modified antenna, IR dome and IR seeker base plate. As expected, very little change has been observed in the errors when the antenna boresight is more than about 15 degrees off the radome nose. However, within this 15 degree cone around the radome nose considerable differences are noted. The results of these tests are currently being compiled and will be forwarded in the next monthly report.

WORK TO BE DONE NEXT REPORT PERIOD

Several components are currently being constructed and assembled in the machine shop. These are:

1. bearing cups;
2. string adjusters;
3. IR seeker base plate.

Work on these items will be completed by the anticipated delivery date of 15 June.

COST INFORMATION

The following charges have been incurred against the contract during this report period.

Personal Services (PS)	$ 5,617.93
Materials and supplies	431.25
Travel	348.01
Fringe Benefits	961.62
Overhead	3,210.81
TOTAL	$ 10,569.62

The current financial status of the contract is as follows:

NONMENCLATURE	BUDGET	EXPENDED	FREE BALANCE
Personal Services	$ 24,015.00	$ 5,617.93	$ 18,397.07
Material & Supplies	1,098.00	431.25	666.75
Travel	3,030.00	348.01	2,681.99
Fringe Benefits	5,043.00	961.62	4,081.38
Overhead	15,664.00	3,210.81	12,453.19
TOTAL	$ 48,850.00	$ 10,569.62	$ 38,280.38

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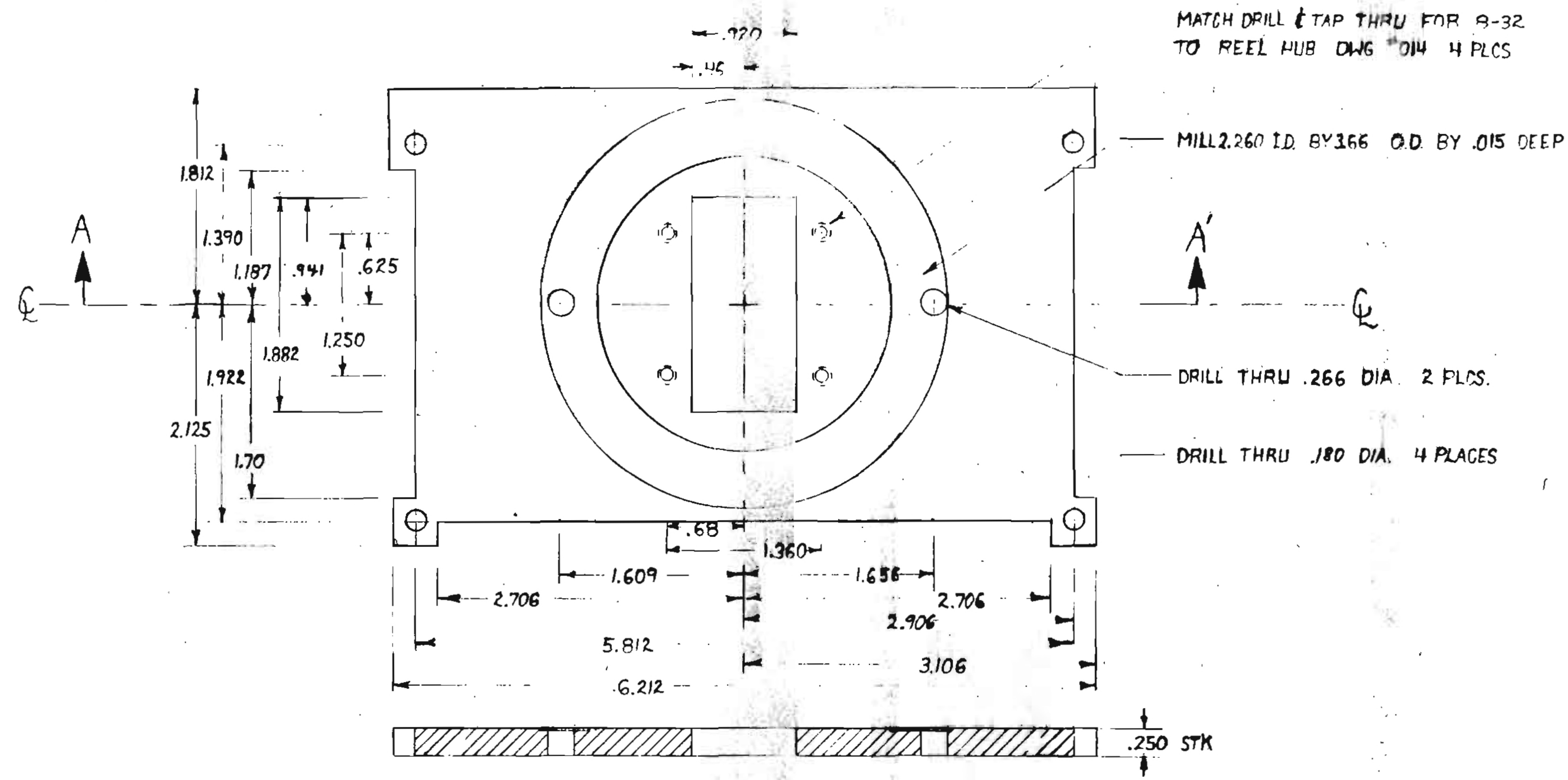
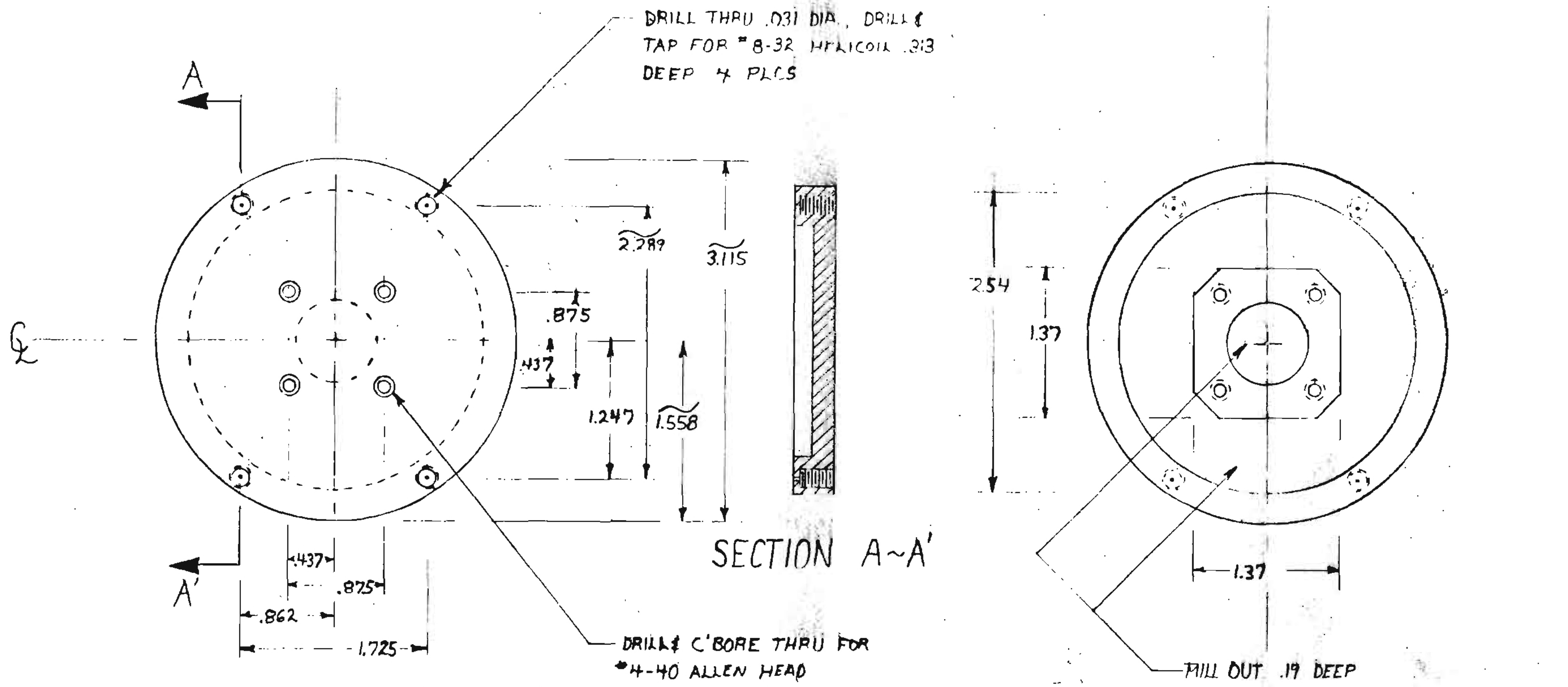


SECTION A~A'

CONTRACT NO.		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA		
DWN MAL	4-8-83	BASEPLATE		
ENGR				
CHK				
PROD				
APVD		SIZE B	CODE IDENT NO.	DRAWING NO. A-3447-016
APVD		SCALE FULL		SHEET

AF 26393A

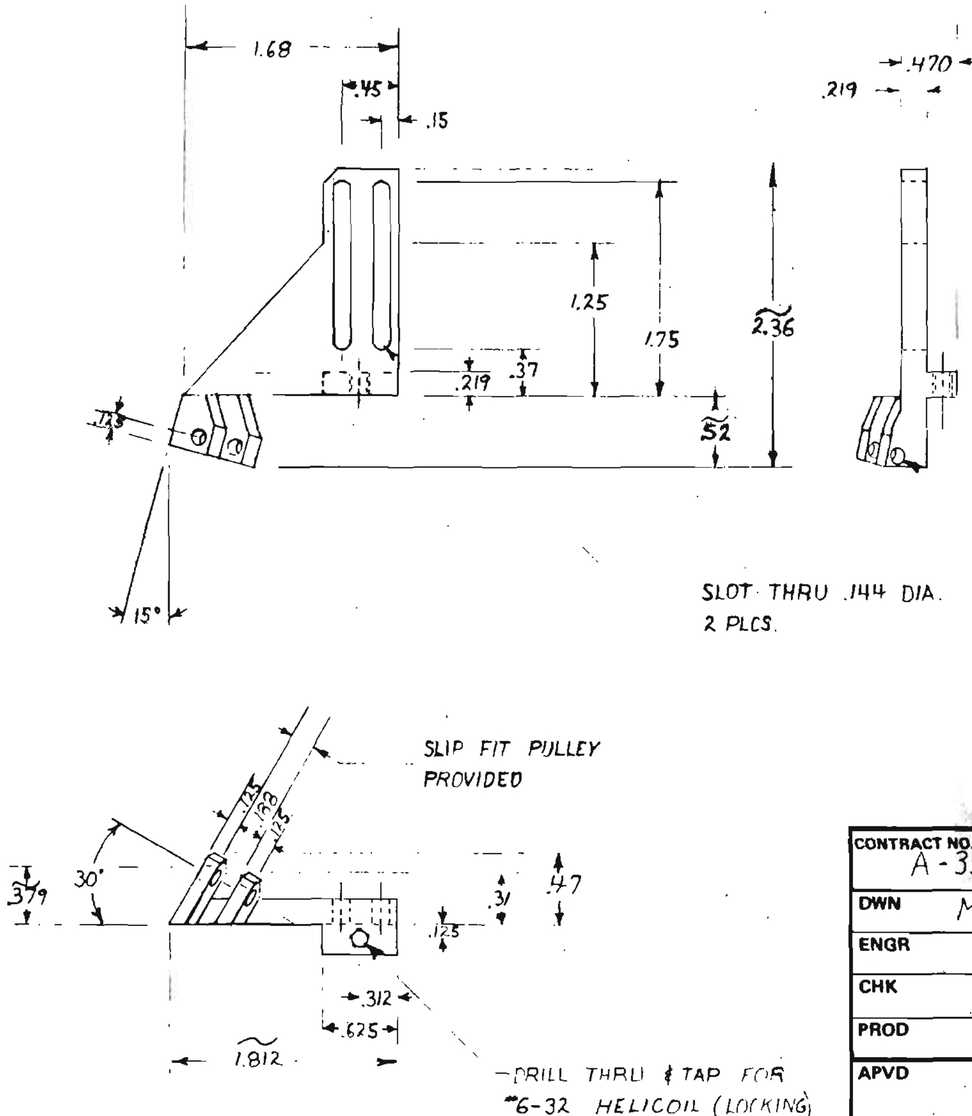


NOTES:

1) MAT'L 3/8" STK G-10 FIBERGLASS
2) TOLERANCES: .XXX ±.005

CONTRACT NO. A-3447-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA
DWN MAL	4-22-83	IR SEEKER MOUNT PLATE
ENGR		
CHK		
PROD		
APVD		SIZE B / CODE IDENT NO. / DRAWING NO. A-3447-021
APVD		SCALE FULL / SHEET

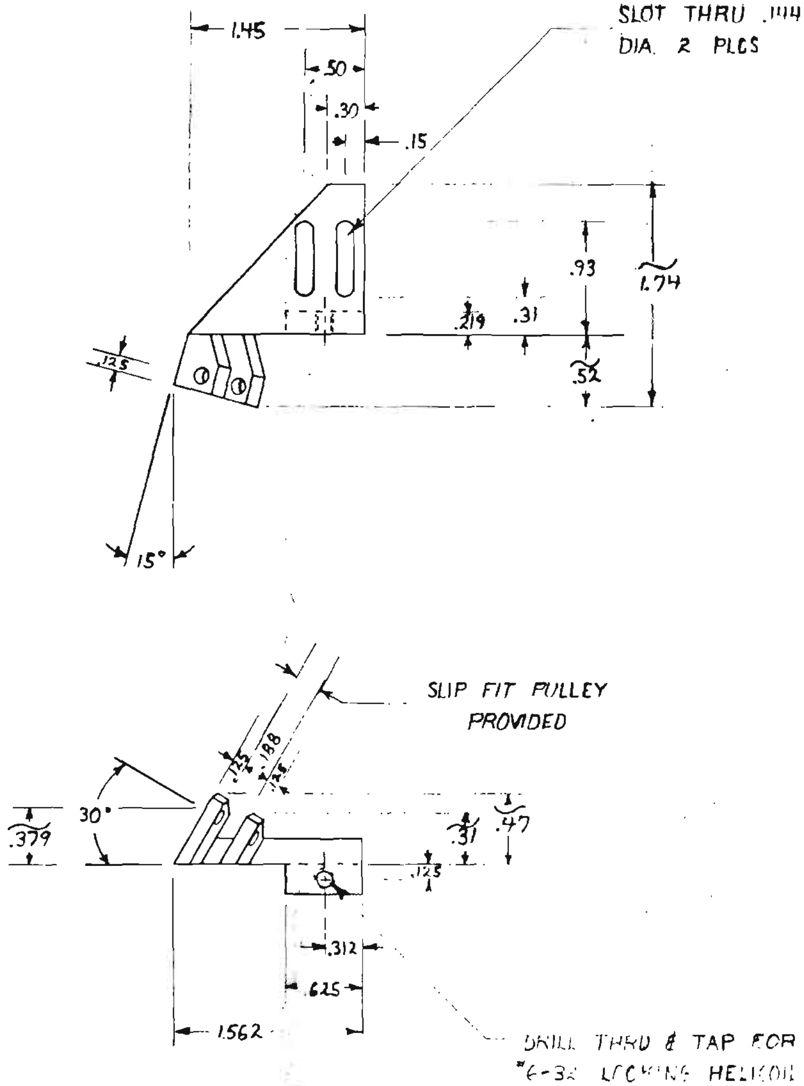
LF 26393A

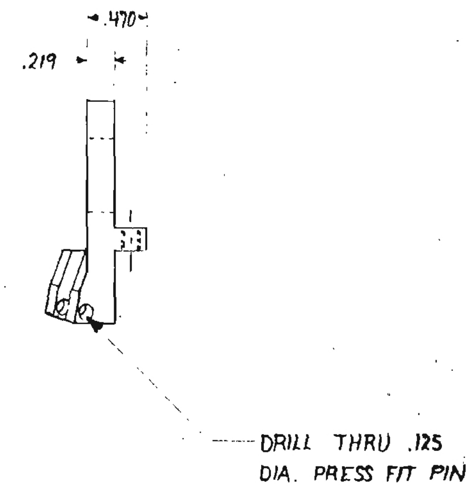


NOTES:
1) MAT'L ALUM.
2) TOLERANCES: .xxx ± .005
.xx ± .01

CONTRACT NO. A-3532-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA			
DWN	MAL	5-10-83	SUM RT. STRING ADJUST		
ENGR					
CHK					
PROD					
APVD			SIZE B	CODE IDENT NO.	DRAWING NO. A-3447-022
APVD			SCALE FULL		SHEET

AF 25393A





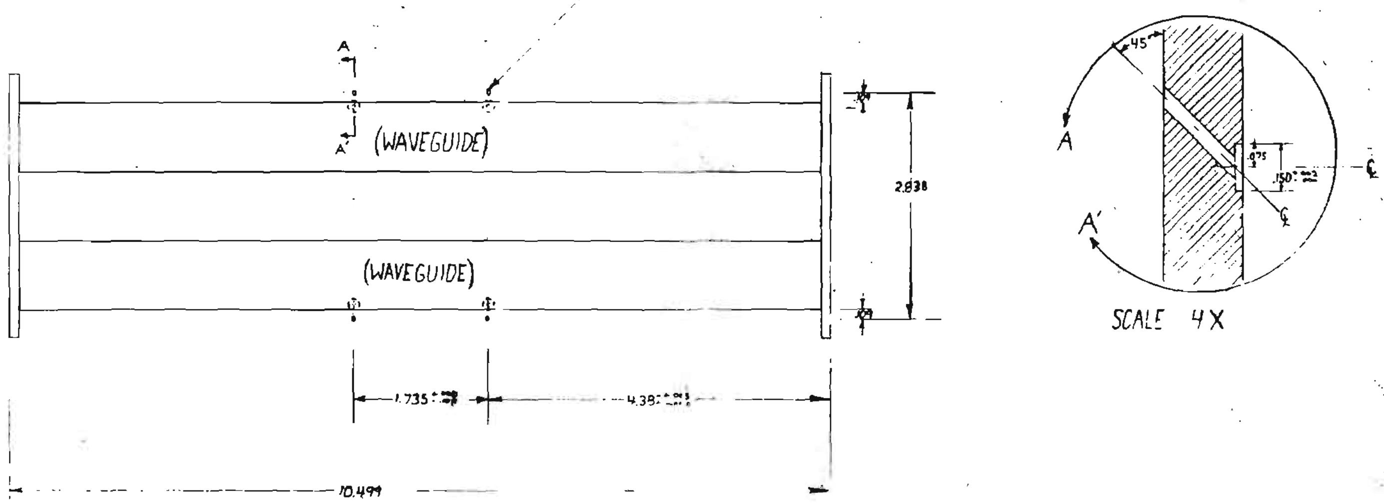
NOTES:
1) MAT'L ALUM.
2) TOLERANCES : .XXX ± .005
.XX ± .01

CONTRACT NO. A-3532-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA	
DWN	MAL	5-11-83	AZ. LT. STRING ADJUST
ENGR			
CHK			
PROD			
APVD		SIZE B	CODE IDENT NO.	DRAWING NO. A-3447-023
APVD		SCALE FULL	SHEET

QTY REQD	NEXT ASSY	USED ON
APPLICATION		

ZONE	SYM	DESCRIPTION	DATE	APPROVED
REVISIONS				

REFERENCE WAVEGUIDE, DRILL THRU AT 45° TOWARD ANTENNAE EDGE .046 DIA, THEN C'BORE OTHER SIDE .190 DIA BY .025 DEEP AT 90°, CENTER C'BORE .007 TOWARD ANTENNAE CENTER



ITEM OR FIND NO.	QTY REQD	NOMENCLATURE OR DESCRIPTION	MATL SPEC AND SIZE OR COMPONENT VALUE	IDENTIFYING OR PART NO.	CODE IDENT.

PARTS LIST

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED
TOLERANCES
3 PLACE DECIMALS ± .005
2 PLACE DECIMALS ±
1 PLACE DECIMAL ±
EXCEPT AS NOTED
FRACTIONS ± ANGLES ± 0°30'
MAX SURFACE ROUGHNESS 125 ALL MACHINED SURFACES EXCEPT AS NOTED
BREAK SHARP EDGES AND CORNERS .010 MAX
FINISH

CONTRACT NO.
DWN MAL 5-17-83
ENGR
CHK
PROD
APVD
APVD

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

ANTENNAE MODIFICATION

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A-3532

MONTHLY TECHNICAL REPORT #8

IRAG Hardware Development
Georgia Tech Project A-3532

Michael Leon
Don Bagwell
Joe M. Newton

Report Period
September 1 through September 30, 1983

Contract #DAAH01-83-D-A013
Delivery Order #10

Effective Date: 5 May 1983
Expiration Date: 30 September 1983

Prepared for

U. S. Army Missile Command
Advanced Sensors Directorate
Redstone Arsenal, Alabama 35898

Prepared by

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

1. Introduction

The purpose of this program was to determine the mechanical methods whereby an IR seeker could be installed in the nose of an IHAWK radome. The basic approach taken was to place the IR seeker in the nose of the IHAWK radome and connect it mechanically to the RF seeker antenna via four Kelvar strings. Perfect tracking between the two antennas will exist if both antennas rotate about pivot points that are equal distances from each antenna. Perfect tracking between the two antennas implies that they are positioned in parallel planes and, consequently, form two sides of a rectangular box with the four strings forming the other four edges. Therefore, the lengths of the four strings will remain equal for all pointing directions. When the concept was reduced to operational hardware it was found that the IR antenna plane moved about a pivot point located closer to the antenna than that of the RF antenna. In this case the lengths of the four strings do not remain constant for all pointing directions. To resolve the problem a spring loaded string take-up reel was placed behind the RF antenna so that constant tension would be exerted on all strings. This allowed the string lengths to change but prevented them from becoming slack and affecting tracking performance.

An IHAWK RF antenna and radome was modified to include the modifications noted and electrical and mechanical tests were conducted at the RFSS in Huntsville, Alabama. These tests proved the mechanical integrity of the modified systems. Many hours of static testing and simulated target intercepts were conducted during this time without any major mechanical problems.

However, during electrical testing it was demonstrated that the IHAWK RF seeker could not perform its intercept function efficiently with the modified radome in place. Oscillations, in the missile guidance loop, were generated when the target crossed into the modified region of the radome. This problem was not anticipated since all input data, from the Army, indicated that the RF seeker did not track in the nose region during an intercept.

Theoretical radome calculations, done after the RFSS tests, show large boresight errors and error rates exist in the nose area. These calculations indicate that boresight error slopes greater than 100% are created when a five inch section of the radome nose is obstructed. This is thought to be substantially greater than the IHAWK seeker can tolerate, thus the oscillations. However, if the size of the obstruction is reduced to approximately 2 to 3 inches, a reasonable track might be achieved. This is subjective, however, since relatively large error slopes still exist.

2. Final Mechanical Report

The purpose of the mechanical effort was to mount a model infrared seeker, Dwg. #21 (see Appendix) in the front of an IHAWK missile radome. The IR circular disk model was required to track parallel to the IHAWK RF antenna up to 55° in all directions.

The method used to accomplish tracking was demonstrated by a system model, provided by the Army. In this model four strings were used to control the movement of the IR seeker. Parallel tracking can be attained with four strings of equal length if the planes of the RF antenna and IR seeker pivot about points equal distance from the antenna surfaces. The main difficulty arises because the IHAWK antenna pivots about a point about three inches behind it. However, not enough space was available in front of the radome to accommodate the IR seeker's movement about a point matching the RF antenna's distance to its pivoting point. Therefore, the IR seeker was forced to pivot about a much closer point.

This difference, in pivoting distances, required the string lengths to change as the seeker tracked. A spring-loaded reel was used to make the necessary length changes in the strings. This reel, Dwg. #015, was mounted on the back side of the RF antenna in order to prevent radiation blockage to the antenna. Friction in the reel was found to limit tracking accuracy. Therefore, a "Reali-Slim" ball bearing, #KA025CPO, was installed between the reel and its hub, Dwg. #014, to reduce friction to a minimum.

The take-up reel is attached to the back of the RF antenna by means of a baseplate, Dwg. #016. Four bolts hold the reel to the baseplate which is sandwiched between the antenna and its gimbal mount. This effectively moved the RF antenna forward of its original mounting location by 1/4", the thickness of the baseplate.

Routing the strings from the reel through to the front of the RF antenna required the string to change direction by 90 degrees. To accomplish this, an Idler pulley, Stock Drive Products,#669-0084, was used to direct each string from the reel to a hole through the antenna. It was evident that more string adjustment was needed than could be achieved at the seeker end alone. However, string adjuster, Dwgs. #022, 023, 026, was added for each string in order to change the length of the string path on the back side of the RF antenna. It is these string adjusters located on the IHAWK RF antenna that made a second radome with access holes necessary.

The holes through the antenna were the determining factor in most of the dimensions for the seeker assembly. The IHAWK antenna is made of waveguide that cannot be punctured without making the antenna useless. Consequently, the only place to drill through the antenna was between the walls of adjacent waveguides. The two walls allow a hole of .046" dia. without breaking through into the waveguide. The holes also had to be drilled outside the two waveguides that run across the back of the antenna (see Dwg. #024). The final spacing of these four holes had to be duplicated on the seeker to attach the strings. It was this hole pattern that set the size of the IR seeker's mounting plate.

Wear on the strings as they worked back and forth through the holes in the antenna was a major cause of string failure. To combat this wear a ruby bearing was added on the front of each of the holes. Each bearing was secured in a bearing cup, Dwg. #024. The cup was crimped to hold the bearing in. The RF antenna was counter-bored .025" deep and the cup was glued in the counter-bore.

Radiation blockage to the antenna was kept to a minimum. This was done by making the IR seeker as small as the hole string pattern would allow. Fiberglass (grade G-10) was chosen because of its strength as the material for the seeker assembly. The IR gimbal, Dwg. #013, was the only part in the assembly not made of fiberglass.

Two radomes were necessary, one for tests and the other for string adjustment. This made it necessary to change radomes without affecting the string adjustment. Both radomes were modified, Dwg. #017, to accommodate the radome sleeve, Dwg. #020. The radome sleeve seats firmly in the modified radome from the front. This creates a removable support for the IR gimbal. The slots in the radome sleeve and the pins in the gimbal mount, Dwg. #019, allow easy positioning and removal of the seeker assembly. The seeker assembly is slipped into the radome without detaching the strings. The sleeve is then swapped from the one radome to the other.

The IR seeker mount plate was attached to the IR gimbal to allow the 55^{o} freedom of movement. The IR gimbal was mounted in the front of the radome on the gimbal mounting plate set in the radome sleeve. The size of this assembly was minimized for the given string pattern. Tracking was accomplished by the four strings and the spring-loaded take-up reel. To insure parallel tracking, the strings are adjusted through access holes in the extra radome.

3. String Replacement Procedure

1) Remove IR dome: Push in the 3 dowel pins, located where the radome and IR dome meet,then pull IR dome straight forward.
2) Detach IR seeker from assembly from radome: Reach into the hole vacated by the IR dome and grasp the seeker mounting plate. Pull IR seeker forward 2/10 of an inch, then twist counterclockwise. The seeker will then be free to slide back into the radome.
3) Remove the radome: Turn the radome counterclockwise and pull forward. Once the radome clears the antenna catch the seeker assembly before it falls.
4) Remove the antenna: The semi-rigid coax coupling, from the local oscillator power divider to the sum and azimuth mixers must first be detached. The coax from the missile body to the power divider must also be disconnected. Once this is done, remove the four bolts that hold the antenna to the gimbal, and the antenna will fall free.
5) Remove take-up reel and spring: Take out the four bolts that secure the reel hub to the baseplate. Turn the reel and hub over. Pull the outside end of the spring from its slot to access the four string holes.
6) Replace string: The string must be one continuous strand allowing for a loop at one end. The hole through the ruby bearings matches the O.D. of the string. To thread the string through the antenna, loop a fine wire through the loop on the end of the string. Feed this wire through the bearing in the front of the antenna. Pull the string through the antenna, over the idler pulley and through the hole in the reel. Tie a large knot on the end of the string

inside the reel to keep it from pulling through the hole. Replace the spring and bolt the hub back on the baseplate. Mount the antenna on its gimbal and reconnect the three coax that were disconnected.

7) Attach the string to the IR seeker mounting plate: Feed the free end of the string through the square hole in the gimbal mount, Dwg. #019, then through the corresponding hole in the seeker mount plate. Leave this end free for now.

8) Mount the radome with access holes: Set the seeker assembly in the radome. Align the radome and turn clockwise to alignment marks on side of radome and missile body.

9) Mount the seeker assembly in the front of the radome: Slide the radome sleeve, Dwg. #020, into the front of the radome and align the marks. Make sure the strings are not twisted. Pull the assembly into the radome sleeve. Twist clockwise, then push in.

10) Secure string(s): (If just replacing one string) Pull replacement string until it is as tight as the three other strings. Knot the string where it comes through the seeker mount plate. (If replacing all four strings) Pull all four strings evenly, then mark and knot the strings where they emerge from the seeker mount plate.

11) Adjust string(s): Loosen bolt in slot of string adjuster, Dwgs. #022, 023, 026. Then loosen or tighten string by running out or in, respectively, the tapped screw on the adjuster. Also, a very small amount of adjustment can be attained by backing out or turning in the Allen head set screws on the seeker mount plate.

12) Replace the original radome: Repeat steps 3, 8, 9, then install IR dome and dowel pins.

4. Radome Modelling

A. General

The radome model used for the theoretical analysis was an approximation of the HAWK radome. The shape was taken to be a tangent ogive having the basic geometry defined in Figure 4.1; for the model used the values of the parameters are:

$$D = 13.46 \text{ in.}$$
$$L = 48.47 \text{ in.}$$
$$\Delta = 10.75 \text{ in.}$$
$$\delta = 0 \text{ in.}$$
$$d = 10.7 \text{ in.}$$

The monolithic wall was assumed to be E-glass with a dielectric constant of 4.4 and a loss tangent of .016. This resulted in higher boresight error (BSE) values than a previously used dielectric constant of 5.

The wall thickness specified for the radome was a prescription based on actual measurements of the wall. The measurements were approximated by least-squares analysis to form the following prescription:

$$\text{THK(inches)} = (0.282 + 0.0064\theta^2)\cdot$$

$$\cos\left(\frac{\text{DIST}-34\cdot-4\theta}{34\cdot-4\theta}\right)(0.5 + 0.108\cdot \text{ABS}(\theta - 0.628))$$

where DIST = Station referenced to radome tip (inches)

θ = Radome circumferential angle from vertical (radians)

The radome was assumed to be symmetric about the vertical plane. The antenna was assumed to be vertically polarized with a cosine illumination function.

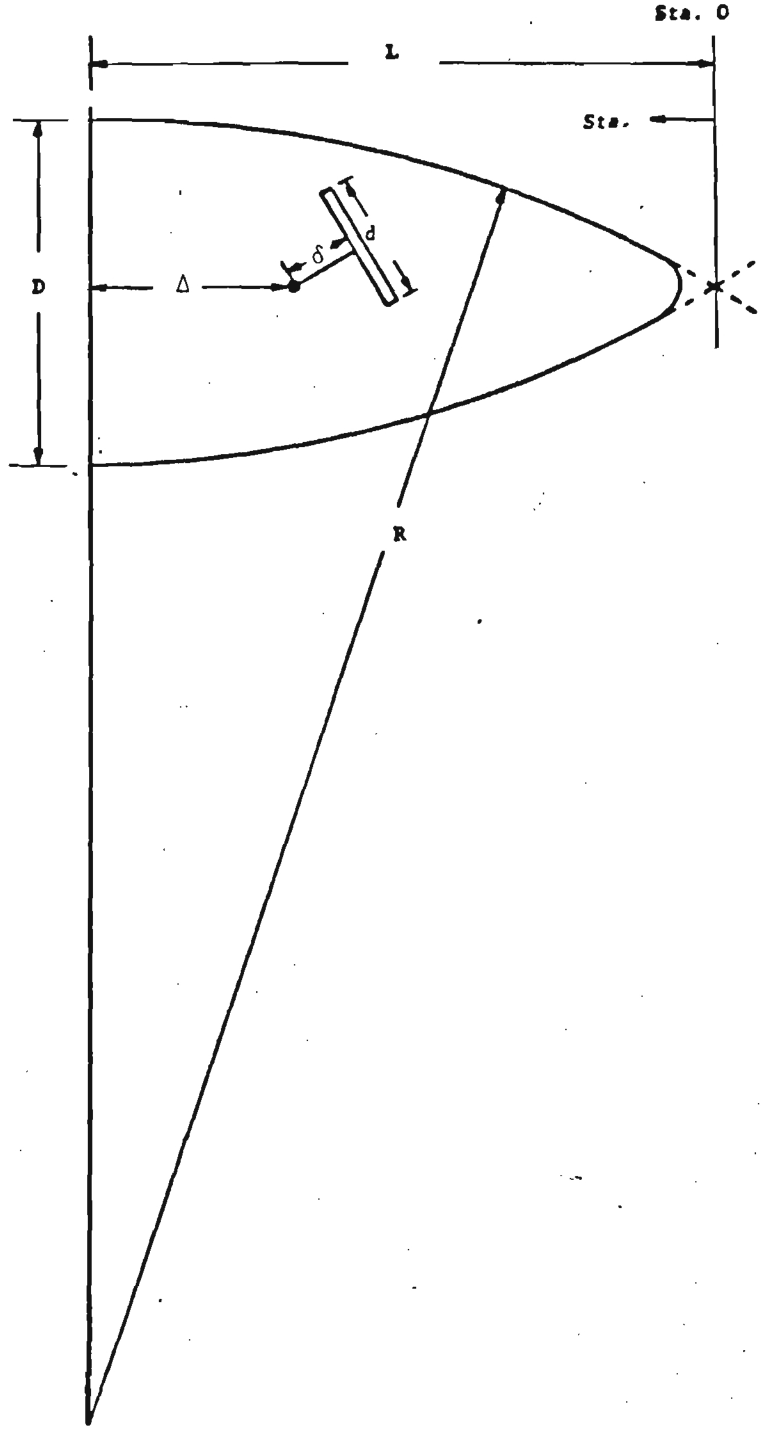


Figure 4.1. Geometry for Tangent Ogive Radome Performance Calculations

B. Analysis

A physical optics (ray-tracing) program was used to model the interaction betwen the radome and the incoming wave. Radome blockages and apertures (apertures implying that the tip of the radome was removed) centered about the radome axis were simulated. The blockages and apertures modeled varied in diameter from 0 to 5 inches. The distance of the blockage or aperture from the antenna was determined from the tangent ogive geometry of the radome. If a real blockage extended closer to the antenna than this position then a larger effective blockage could be used.

The azimuth and elevation BSE's for azimuth and elevation principle planes were calculated for angles off-axis of from 0 to 15 degrees were calculated. The BSE's calculated for blockage are seen in Figures 4.2 and 4.3. The additional BSE errors induced by adding blockage were 0.0 for zero offset angle, rising to a maximum at 4.0 degrees, and then returning to 0.0 again at 14.0 degrees. Direct calculations show that the 4.0 degree offset is the approximate position where the "shadow" of the blockage is centered on half the antenna and that for offsets greater than 15 degrees the blockage shadow no longer intercepts the antenna. For blockages smaller than 5 inches the return of the BSE curve with blockage to the BSE curve with no blockage occurs at a smaller offset angle. The BSE slopes for different blockages are plotted in Figures 4.4 and 4.5. The slopes approach 100% $\left(\frac{\text{Change Error(Deg)}}{\text{Change Angle(Deg)}} \times 100\right)$ for a five inch blockage for both the azimuth and elevation scans.

The BSE curves for different apertures in the radome are plotted in Figures 4.6 and 4.7. The BSE curves for apertures have larger peak BSE values than the curves for blockage. The direction of the additional BSE added by the apertures is the same (negative) for both the azimuth and elevation scans. This

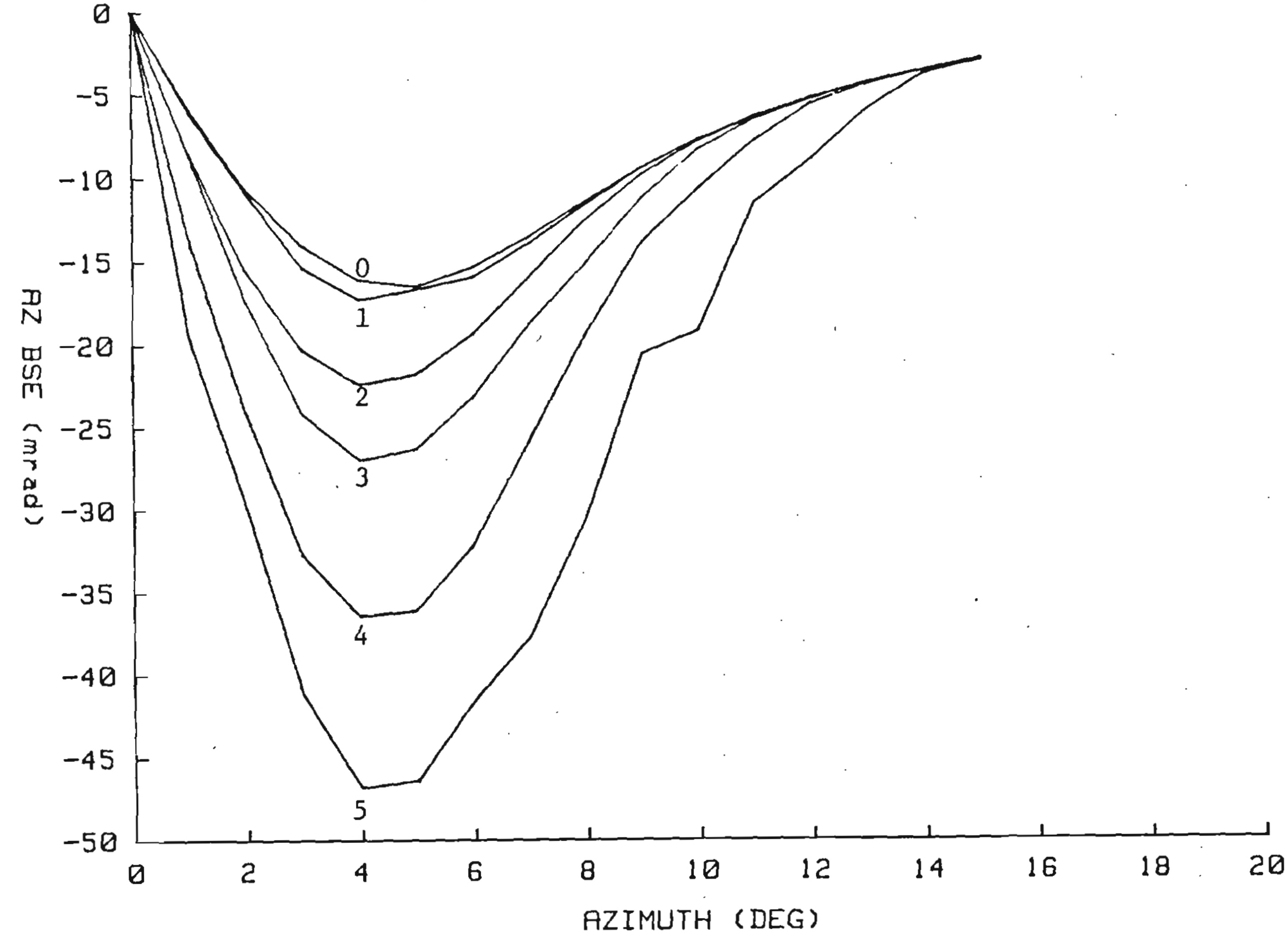


Figure 4.2. Azimuth BSE as a function of azimuth angle for blockages of 0 to 5 inches in diameter.

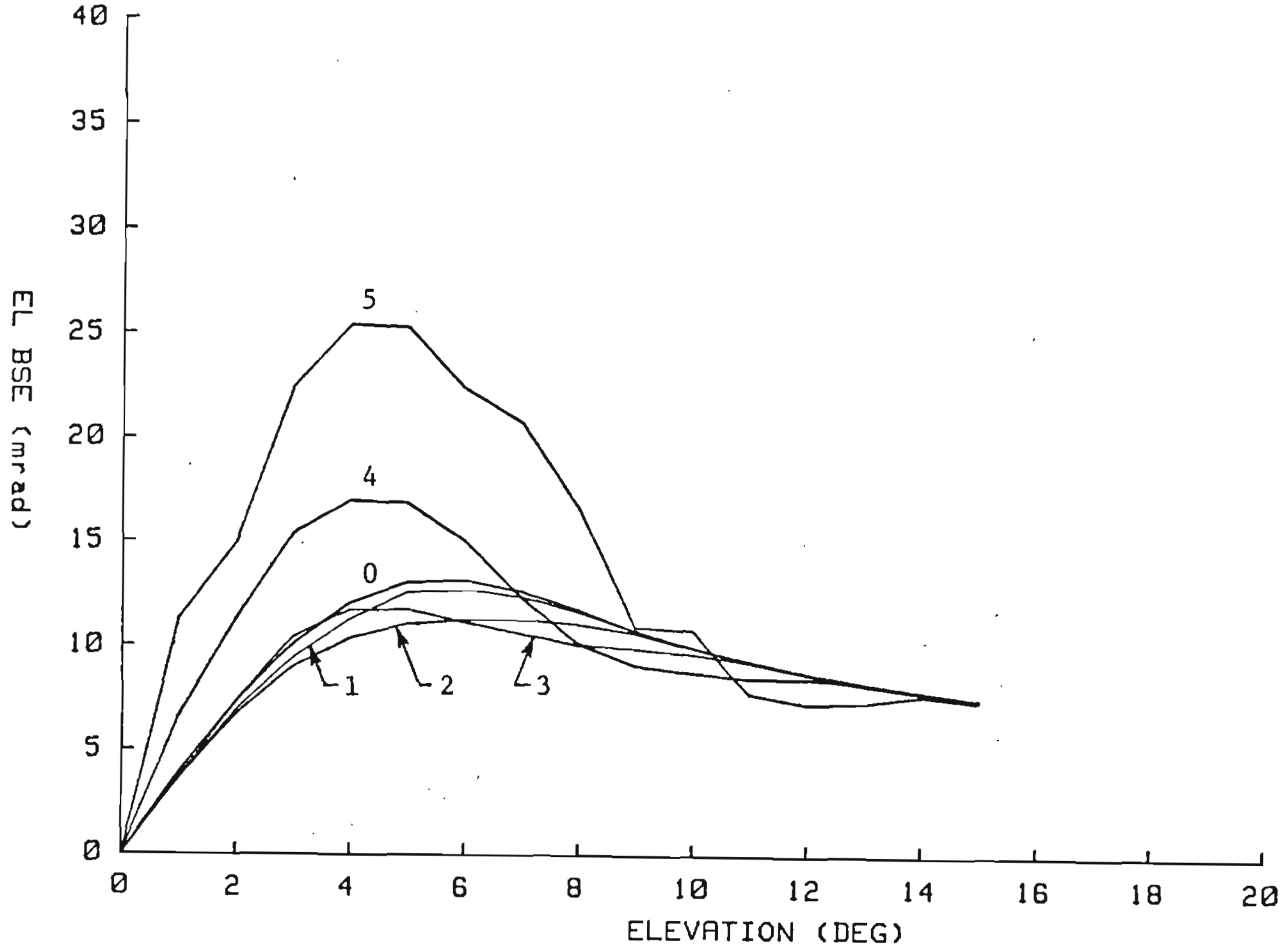


Figure 4.3. Elevation BSE as a function of elevation angle for blockages of 0 to 5 inches in diameter.

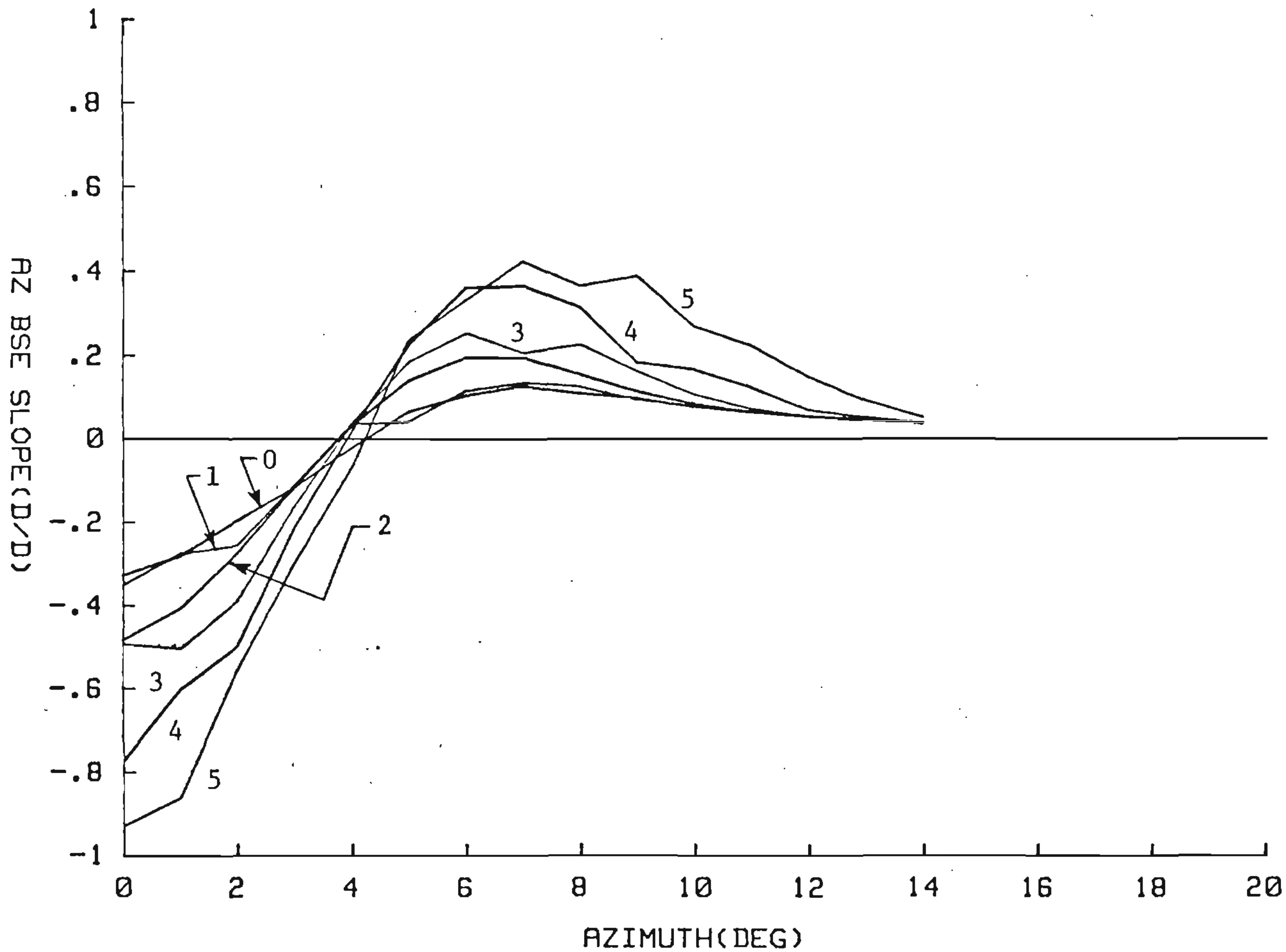


Figure 4.4. Azimuth BSE slope as a function of azimuth angle for blockages of 0 to 5 inches in diameter.

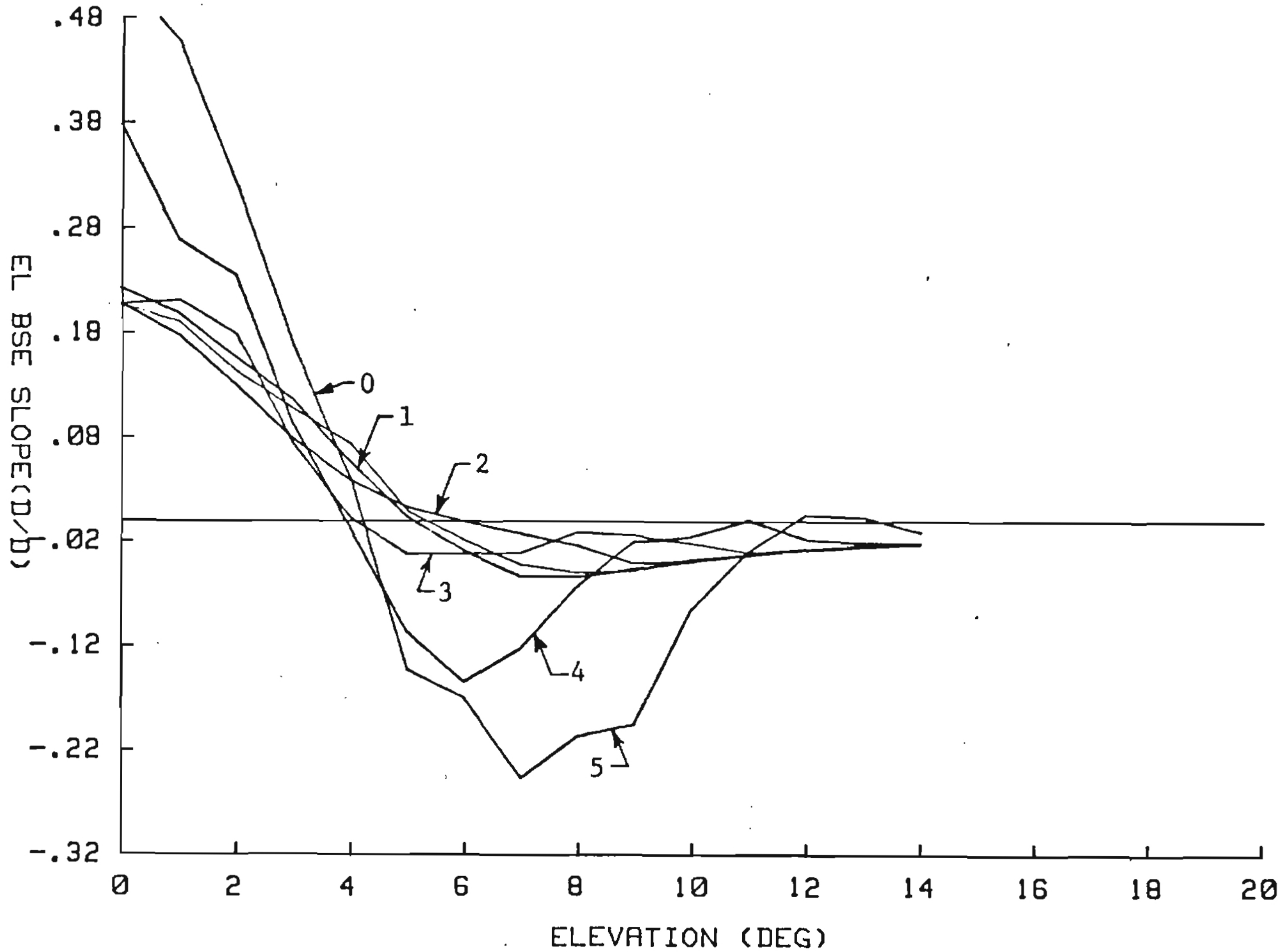


Figure 4.5. Elevation BSE slope as a function of elevation angle for blockages of 0 to 5 inches in diameter.

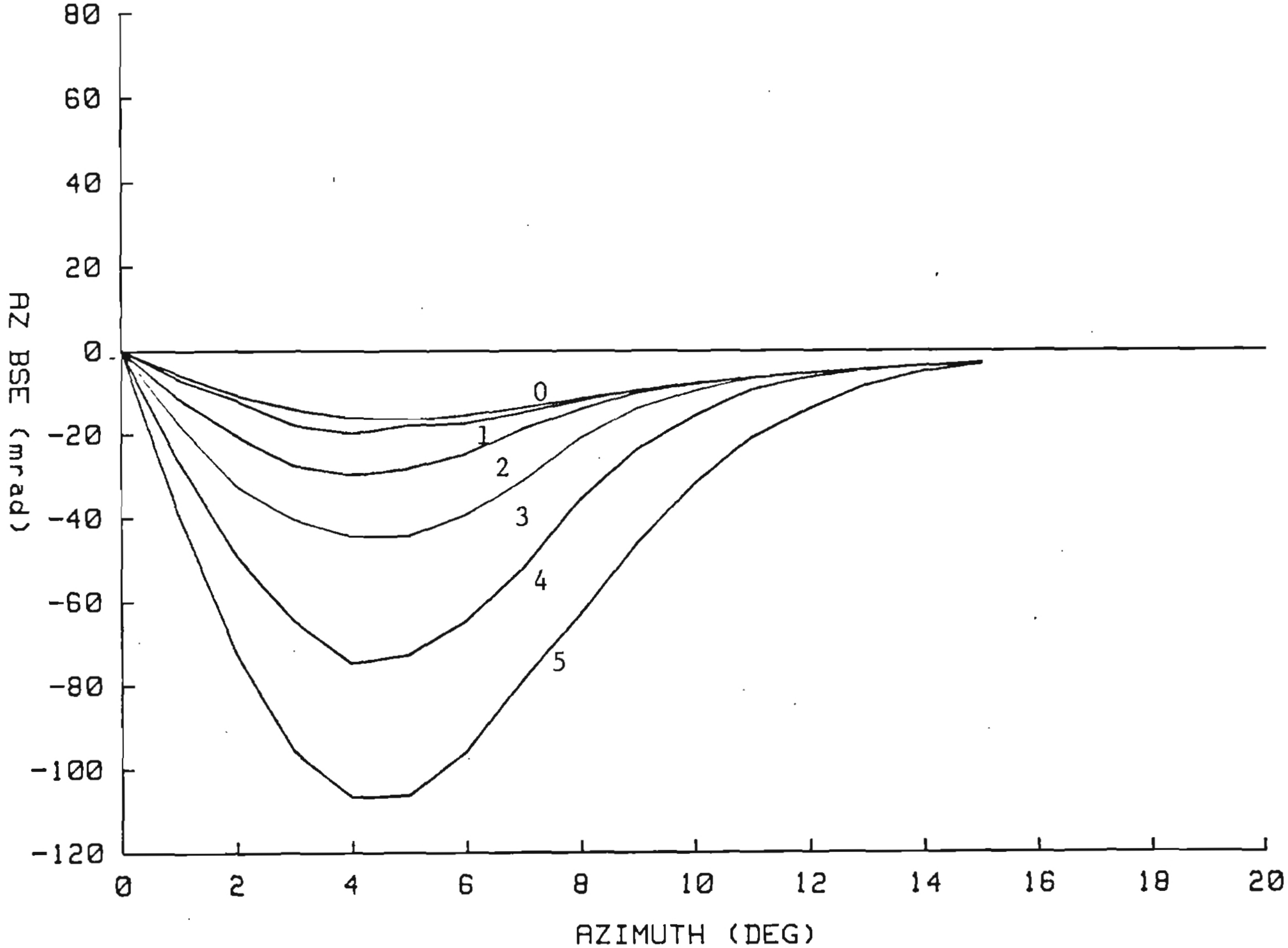


Figure 4.6. Azimuth BSE as a function of azimuth angle for apertures of 0 to 5 inches in diameter.

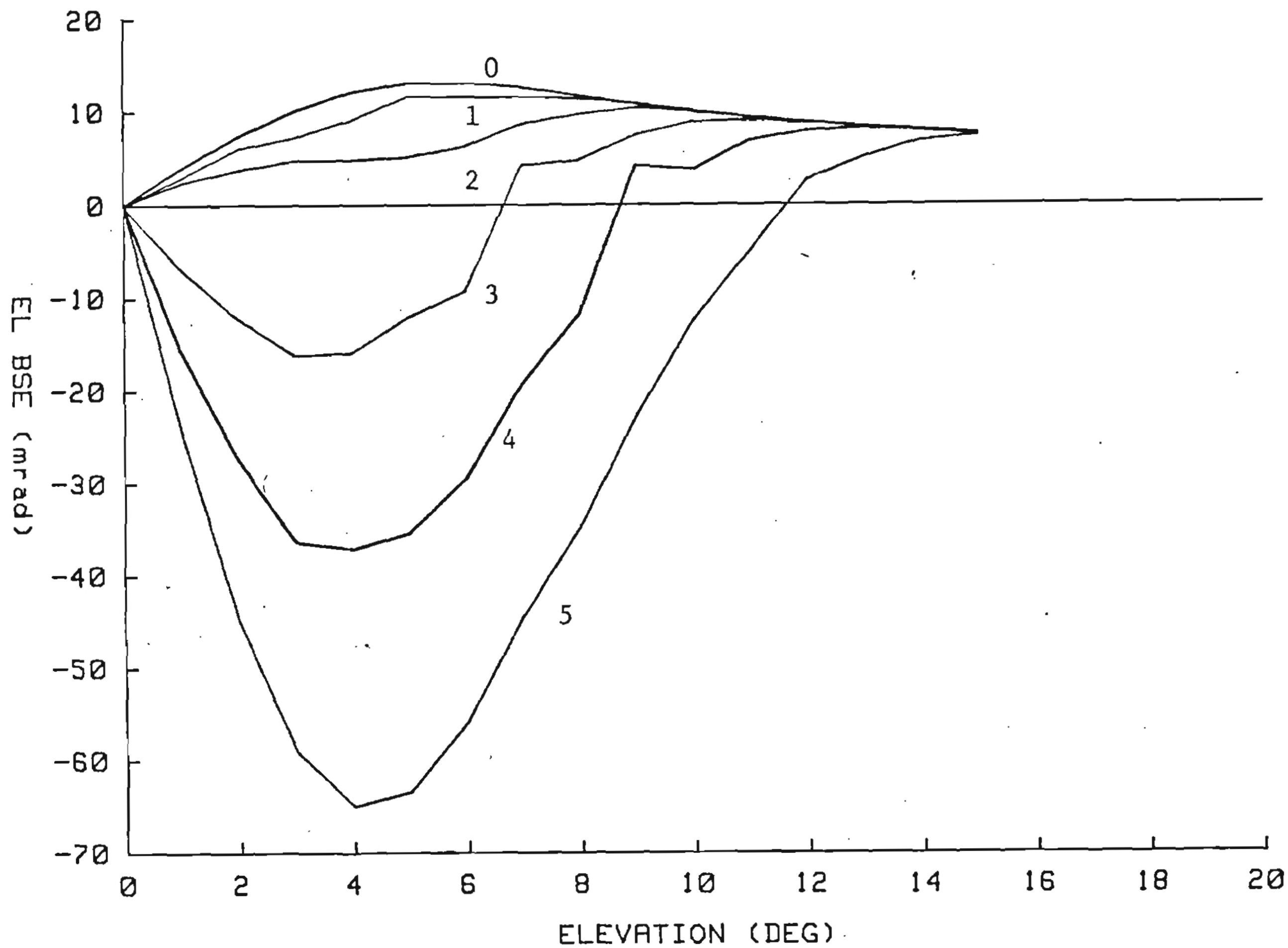


Figure 4.7. Elevation BSE as a function of elevation angle for apertures of 0 to 5 inches in diameter.

contrasts with the BSE's induced by blockage in which they were in the same direction as the original BSE's (no blockage), and the original BSE's were in opposite directions for azimuth and elevation scans. The BSE slopes for apertures in the radome are plotted in Figures 4.8 and 4.9. The slopes get as large as 200 percent for a 5 inch blockage.

C. Results and Conclusions

In all of the boresight error and boresight error slope plots the blockages and apertures of 4 or 5 inches lead to large values for both the boresight error and the boresight error slope. Since the effect of blockage obviously depends on the area of the blockage, this area should be kept to a minimum to reduce errors. The blockages of 4 and 5 inches in diameter have a much larger error slope than the rest. The large errors for an aperture in the radome imply that the rays passing through the aperture are nearly 180 degrees out of phase with those coming through the radome. Any attempt to pass radiation through the desired IR seeker location should make sure that the electrical thickness of the modified region is approximately the same as that of the radome before the modification.

The oscillations observed in the flight simulation are probably due to the high BSE slopes. The large slopes calculated above are above the design limits of the seeker tracking mechanism and electronics. As the missile starts to track through the nose the blockage shadow falls on the antenna and the large BSE's should cause the seeker to over-react in its movement and enter the oscillatory phase. Reducing the BSE values and slopes is the prefered method of minimizing the oscillations. A possible alternative is to store a BSE map in an onboard digital computer. The main disadvantages to this method are that the BSE's are hard to measure accurately and the actual BSE's would

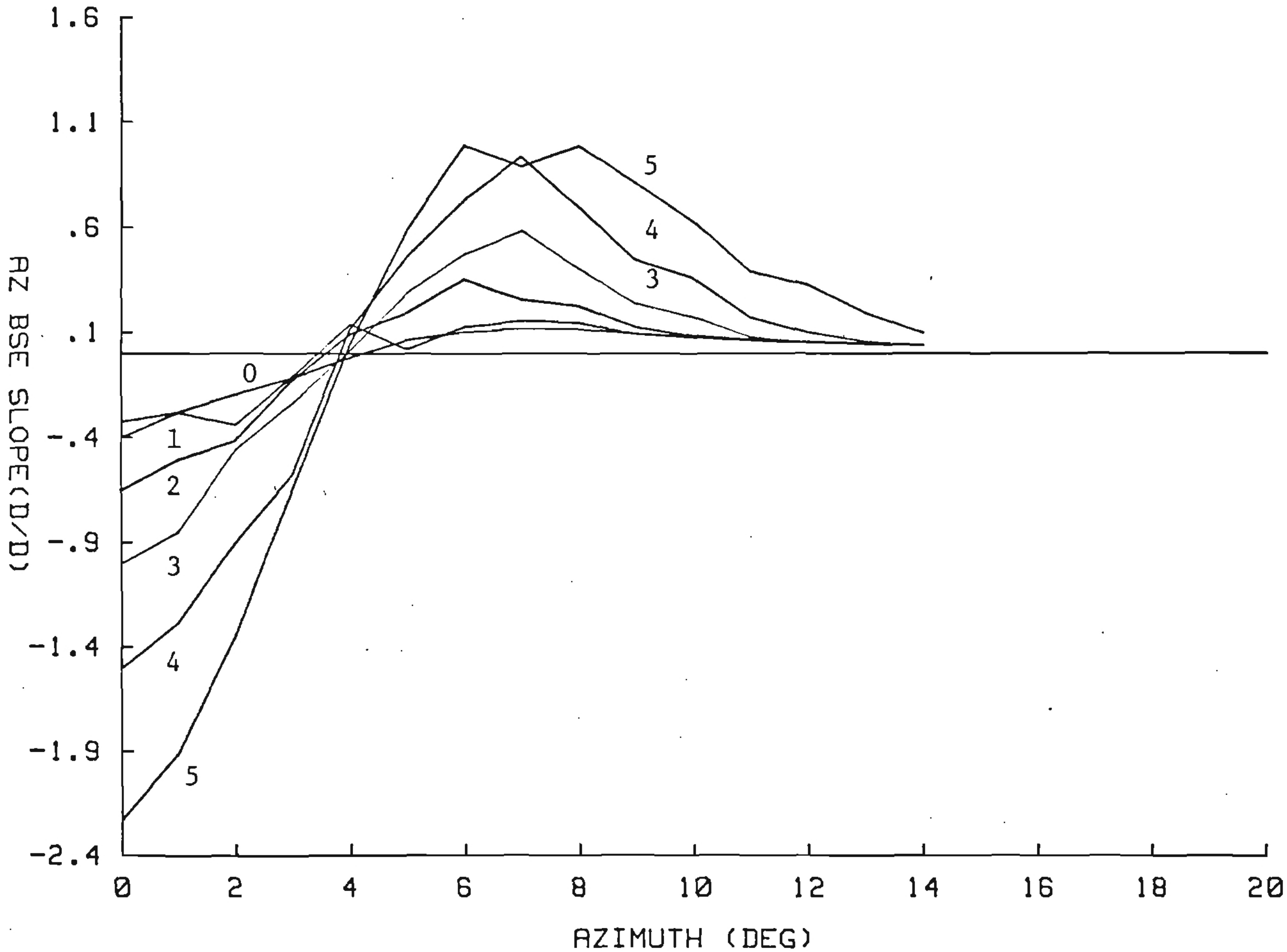


Figure 4.8. Azimuth BSE slope as a function of azimuth angle for apertures of 0 to 5 inches in diameter.

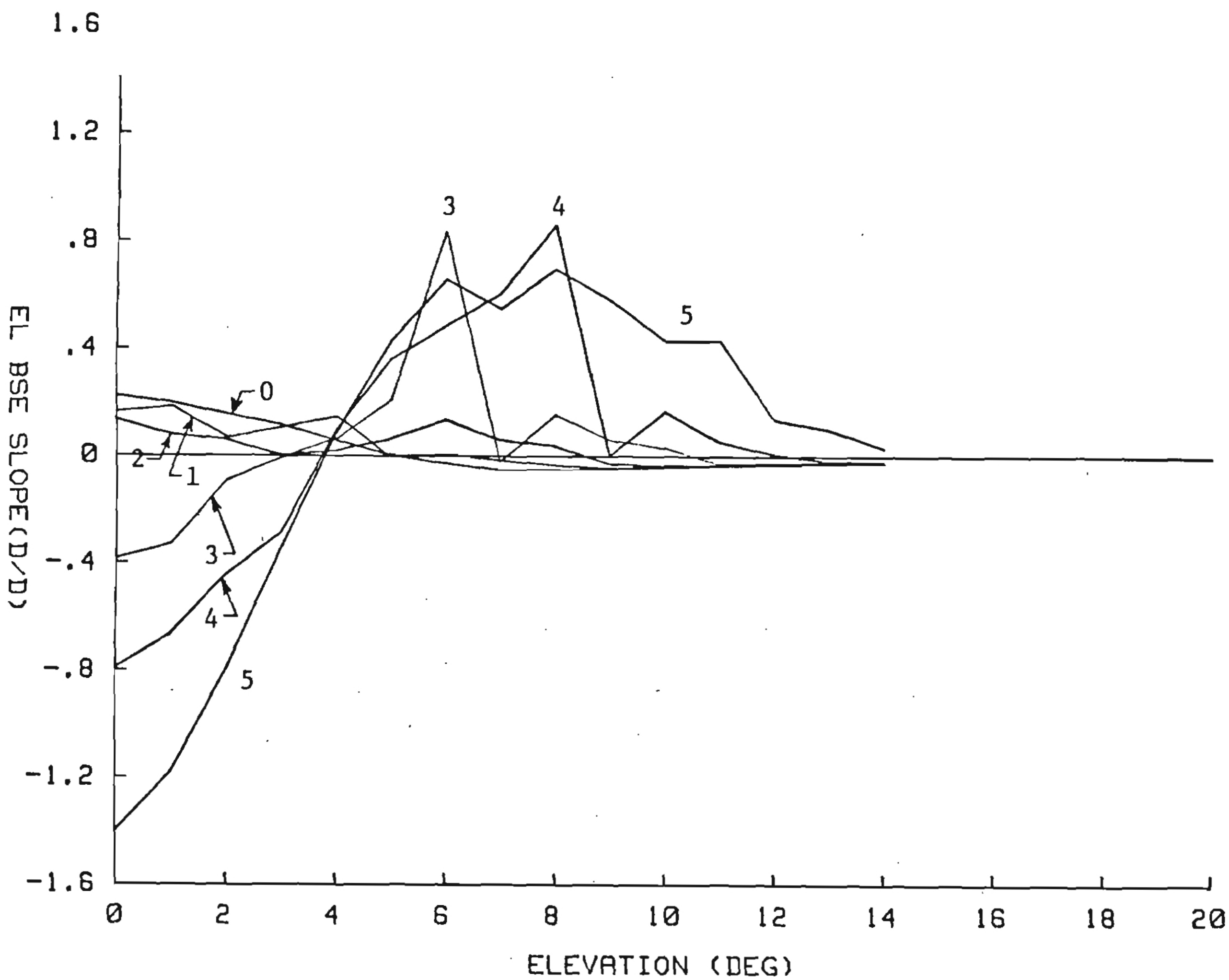


Figure 4.9. Elevation BSE slope as a function of elevation angle for apertures of 0 to 5 inches in diameter.

be target dependent for a resolved target since different areas of the target would appear to be blocked off from different areas on the antenna.

5. Mechanical Constraints on IR Seeker Size Reduction

The Hawk missile was fitted with an infrared seeker mounting plate. This seeker plate was mounted in the radome on a gimbal and was to track parallel to the IHAWK's antenna. The seeker plate utilized 4 strings that ran parallel to one another from the antenna to the seeker plate. The 4 string system proved viable mechanically, but the seeker assembly blocked too much of the radiation going to the RF antenna. This made the RF seeker unstable when tracking straight ahead.

The amount of radiation blockage can be reduced while keeping basically the same seeker and reel assembly designs. It has been determined that a reduction in blockage could be best done by decreasing the size of the seeker assembly (see Figure 5.10). This results in a two fold reduction in blockage. First, the actual blockage area, directly in front of the antenna, is reduced; secondly, the smaller seeker can be moved further from the RF antenna. This increase in distance will also reduce the angle the antenna must move to look around the seeker assembly.

The present diameter of the IR seeker assembly (Figure 5.12) was made as small as the hole pattern for the strings would allow. Therefore, a reduction in the displacement of the holes through the RF antenna would allow the use of a smaller IR seeker. The two waveguides across the back of the RF antenna fixed the largest dimension of this pattern (see Figure 5.10). The only way to reduce this dimension is to drill these holes between the waveguides on the back of the antenna (see Figure 5.11). The strings would cross underneath the baseplate and possibly use the same string adjusters to route them to the reel (see Figure 5.13).

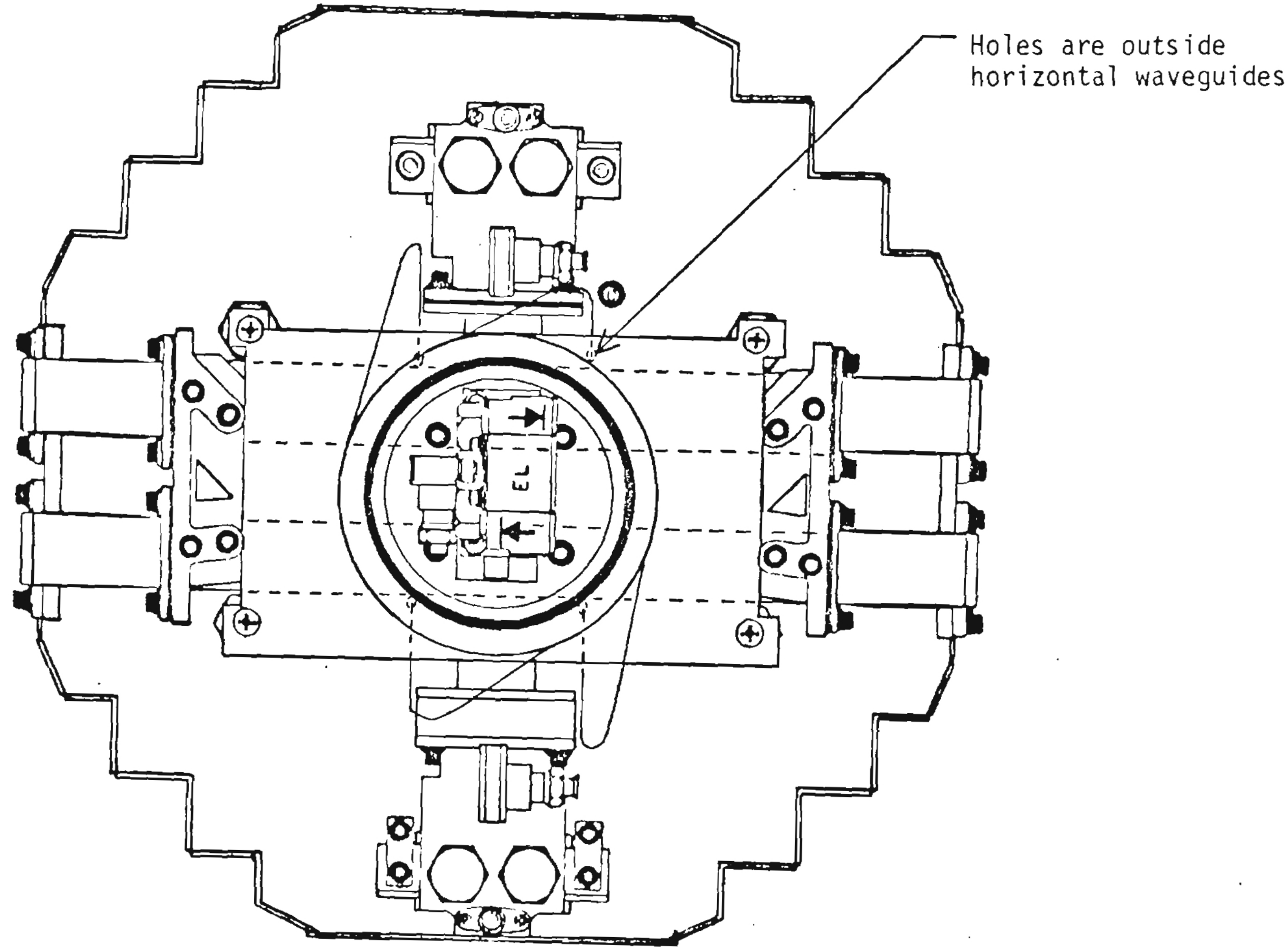


Figure 5.10. Present String Path

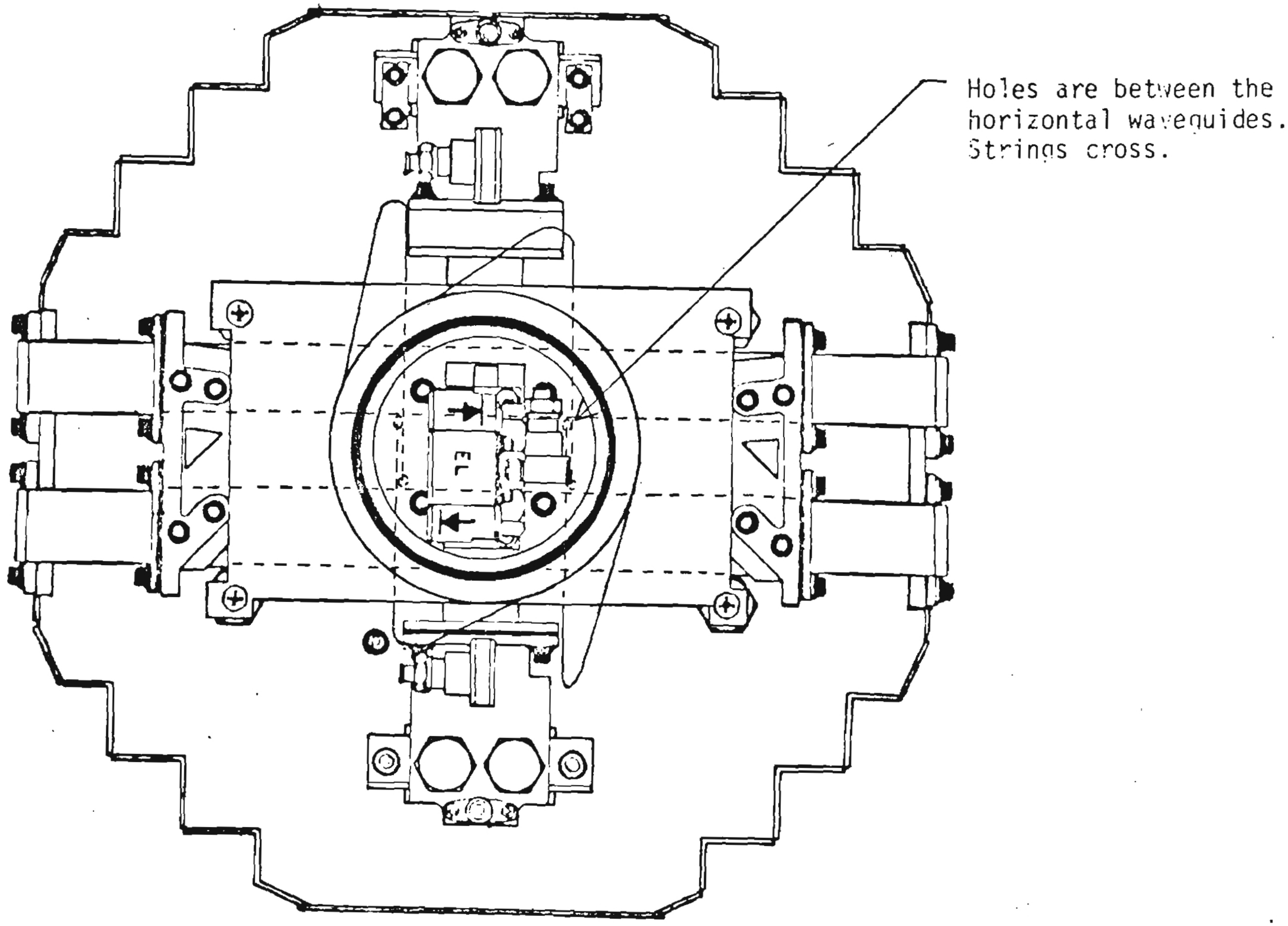


Figure 5.11. Proposed String Path

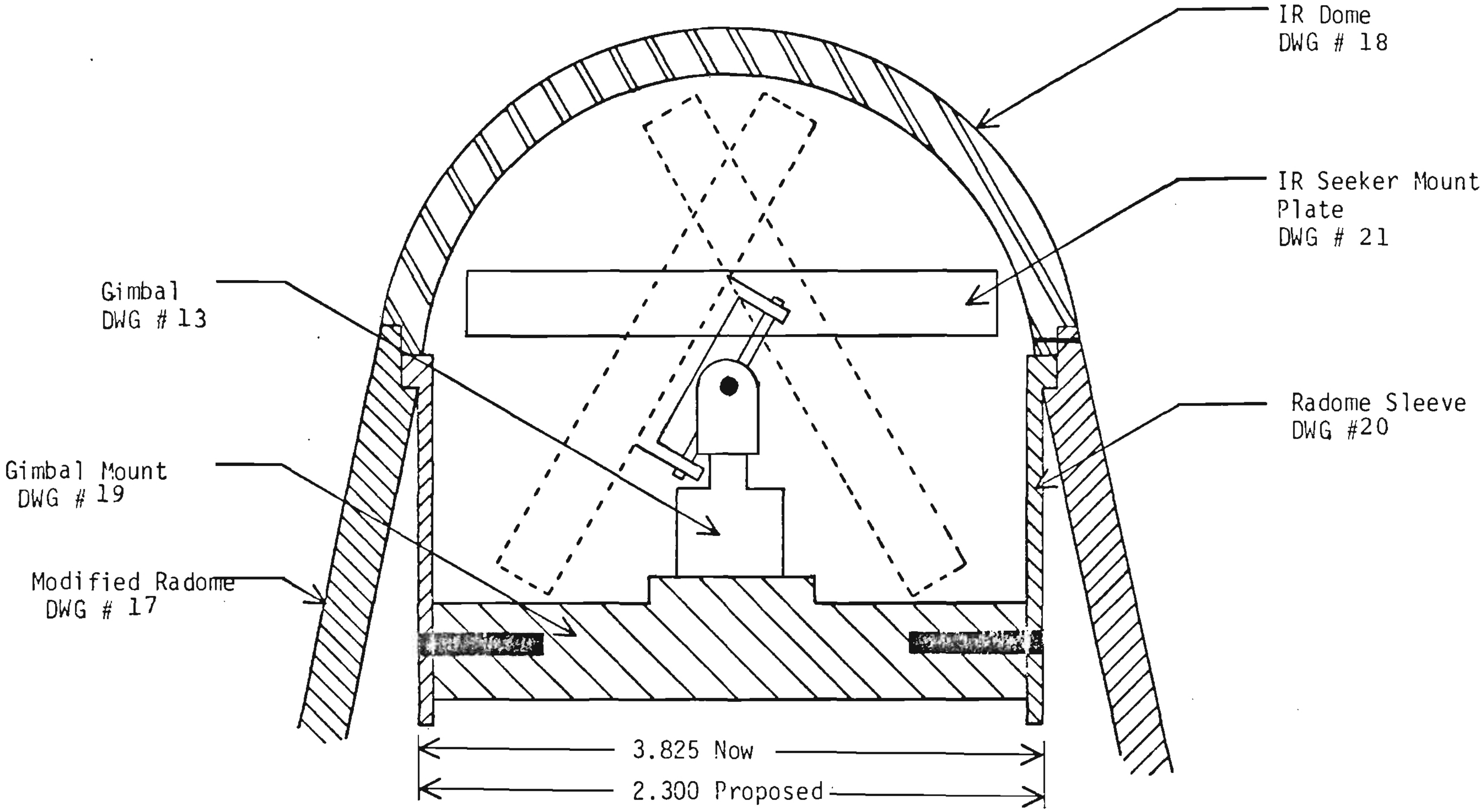


Figure 5.12. Infrared Seeker Assembly

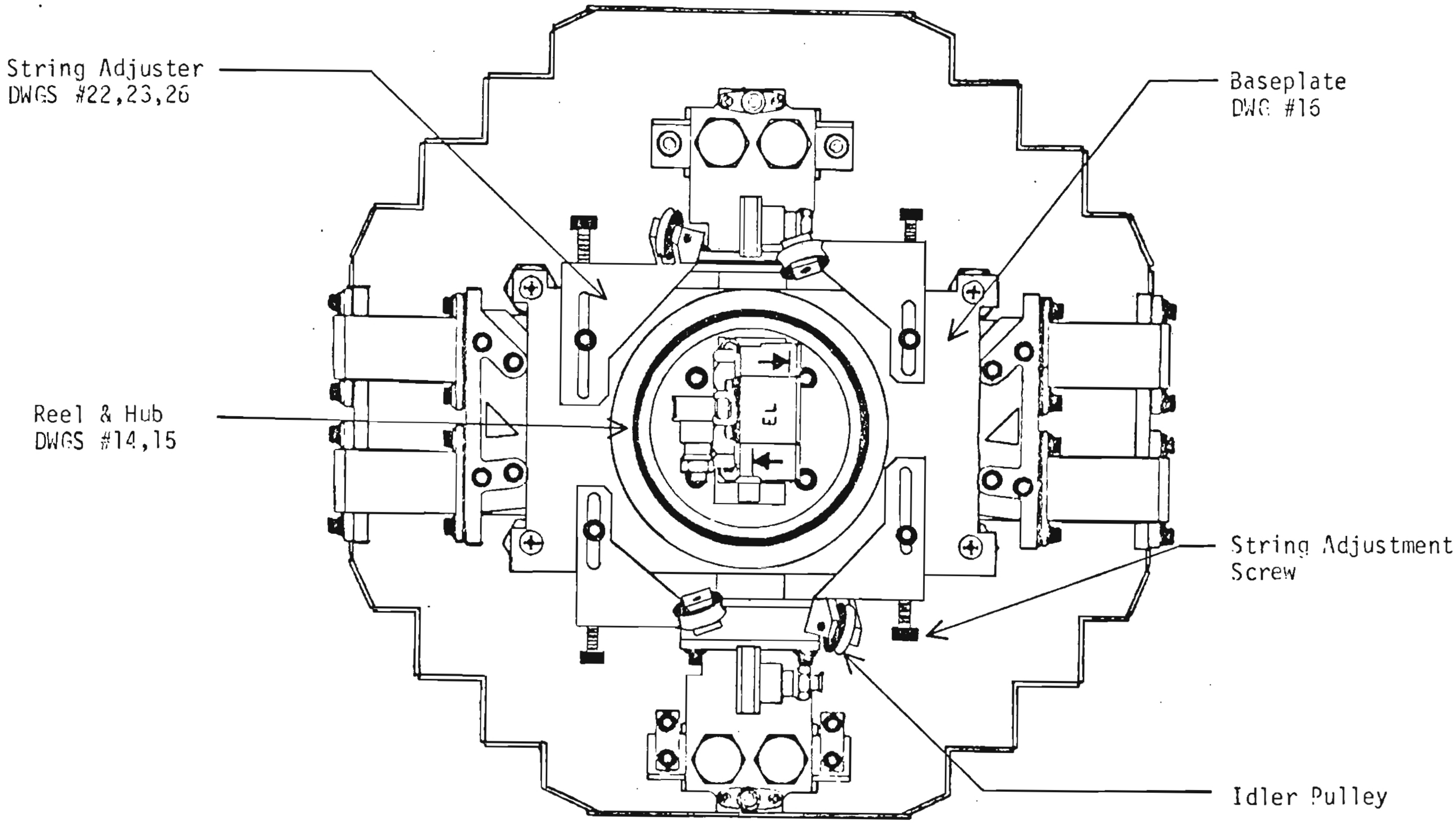


Figure 5.13. Present Reel Assembly

The larger dimension of the hole pattern is the one where the holes are drilled between adjacent waveguide walls. This dimension cannot change without breaking through waveguide. Therefore, this dimension, 1.725 inches, Dwg. #25, controls the diameter of the seeker assembly. The IR seeker mount plate can now decrease in diameter and thickness. With the smaller mounting plate, the radome sleeve diameter can now be reduced to 2.3 inches (Figure 5.12).

The smaller IR seeker mounting plate requires 0.70 inches less space to rotate the required 55 degrees. The IR seeker mounting plate can be 0.125 inches thinner and the gimbal mounting can be 0.1 inches thinner. Therefore, the seeker assembly will be a total of 0.92 inches shorter.

The smaller seeker assembly diameter allows it to mount 3.52 inches forward of the present assembly in the radome. The shorter assembly and the move forward makes the distance from antenna to obstruction a total of 4.44 inches further than the present system. See Table 5.1 for calculations.

TABLE 5.1. CALCULATIONS (SEEKER SIZE REDUCTION)

1.725	+	2(0.032)	=	1.789
holes between waveguide walls		hole clearance		IR seeker mount plate dia.

3.115	-	1.789	=	1.326
existing mount plate				difference

2.10	+	0.100	=	2.300	(proposed
allowing for 1/4" thick IR seeker mount plate clearance for rotation		sleeve		sleeve body	seeker assembly O.D.= 2.300)

3.825	-	2.300	=	1.525
existing sleeve body		proposed sleeve body		diameter difference

0.700 on rotation	+ 0.1	+	0.125	=	0.925 inches
shorten sleeve due to smaller seeker dia.	thickness change of gimbal mount		thinner IR seeker mount plate		total IR seeker assembly length change

x is the distance seeker assembly moves forward

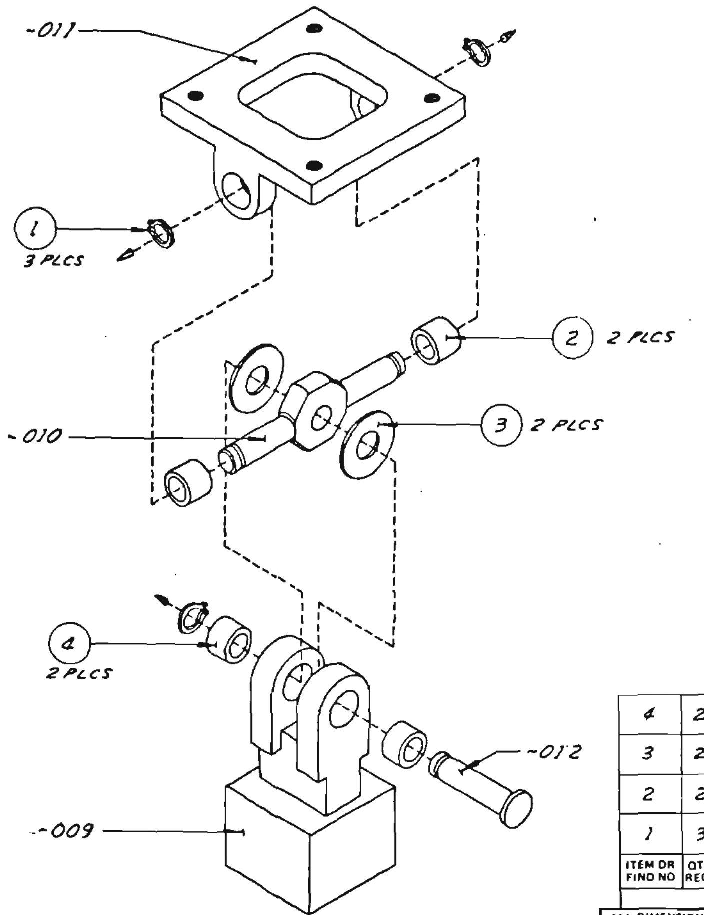
12.5^{o} is approximate radome angle

$x \sin 12.5^{o} = 1.525/2$ $\quad x = 1.525/25 \text{ in } 12.5^{o} = 3.52$

$\underline{+0.92}$

4.44 - actual dist. assembly is moved

APPENDIX



APPLICATION		
QTY REQD	NEXT ASSY	USED ON
1	FINAL	

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVED

ITEM OR FIND NO	QTY REQD		NOMENCLATURE OR DESCRIPTION	MATL SPEC AND SIZE OR COMPONENT VALUE	IDENTIFYING OR PART NO.	CODE IDENT.
4	2		'OILITE' BRONZE	1/8 ID, 3/16 OD x 5/32 LONG		
3	2		'OILITE' BRONZE	1/8 ID, 3/8 OD x 1/32 THK.		
2	2		'OILITE' BRONZE	1/8 ID, 3/16 OD x 1/8 LONG		
1	3		SNAP RING	1/8" NOM. SHAFT		

PARTS LIST

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED
TOLERANCES
3 PLACE DECIMALS ±
2 PLACE DECIMALS ±
1 PLACE DECIMAL ±
FRACTIONS ± ANGLES ± 0° 30'
MAX SURFACE ROUGHNESS 125 ALL MACHINED SURFACES EXCEPT AS NOTED
BREAK SHARP EDGES AND CORNERS .010 MAX
FINISH

CONTRACT NO A3447
DWN WNM 3-16-85
ENGR
CHK
PROD
APVD
APVD

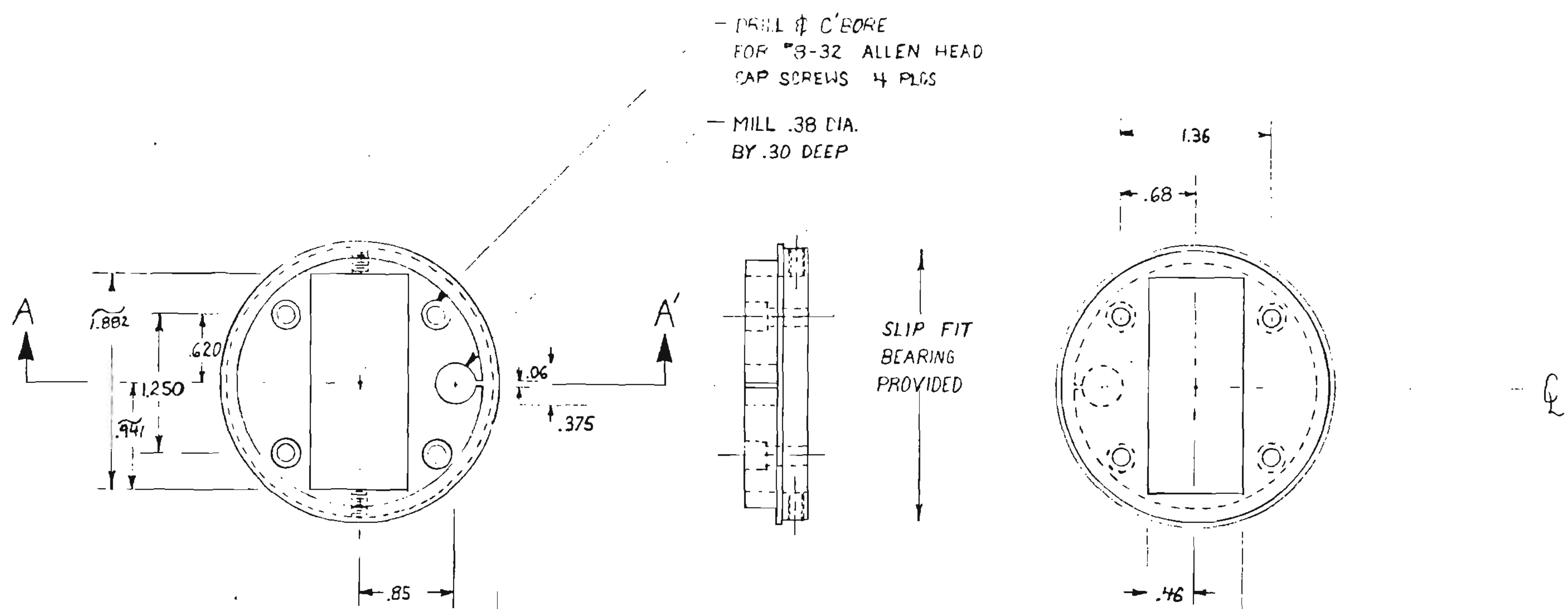
ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA GEORGIA

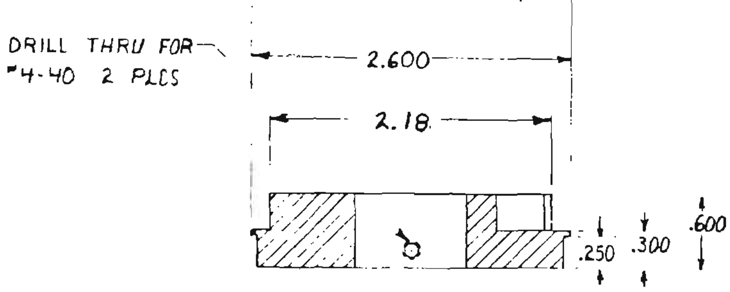
GIMBAL ASSEMBLY

SIZE C | CODE IDENT NO. | DRAWING NO. A3447 - 013 | REV

SCALE 2X | SHEET

A3447-013





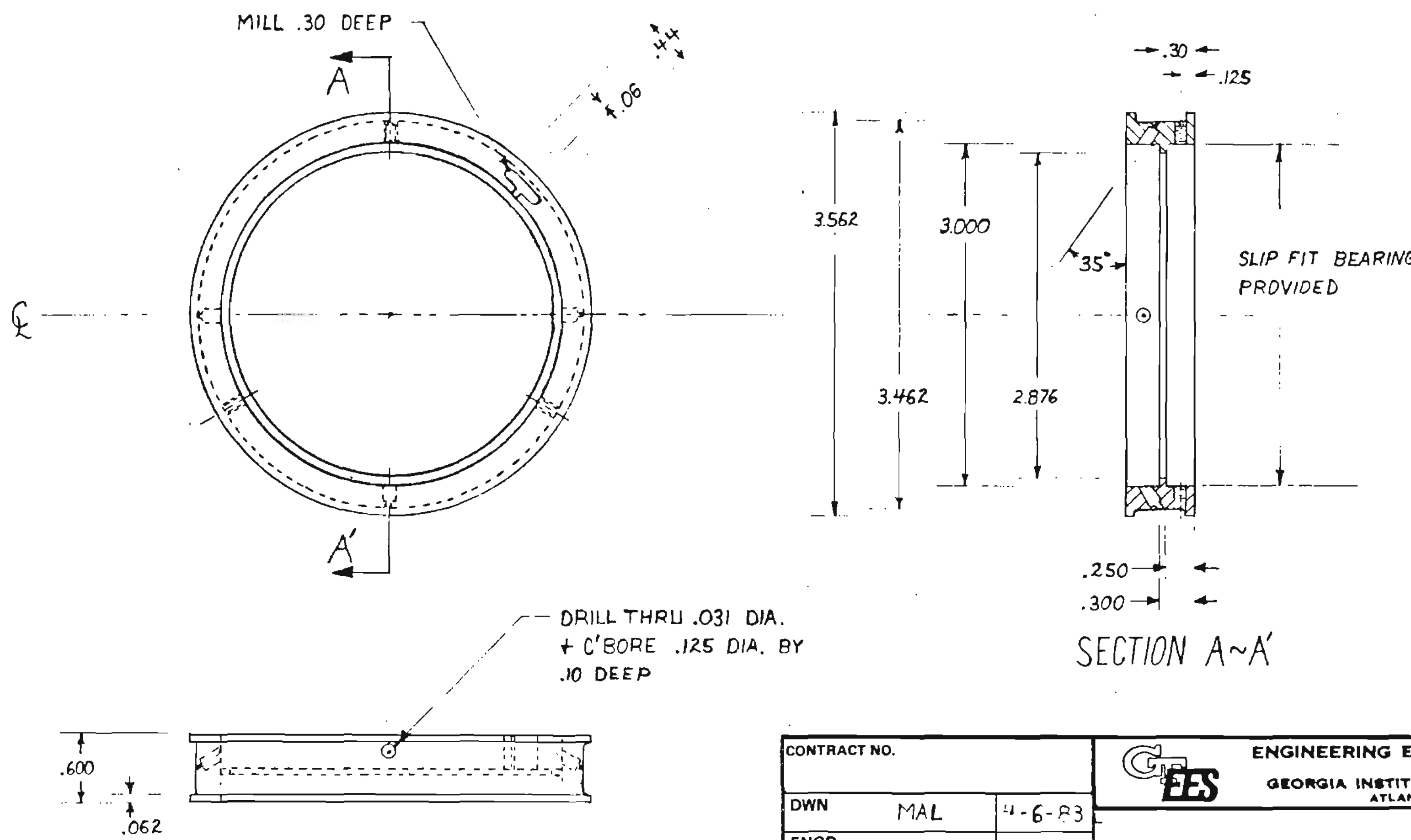
SECTION A~A'

NOTES:

1) MAT'L: ALUM. 6061 - T6
2) MATCH DRILL #8-32 CLEARANCE HOLES WITH BASEPLATE DWG # 016
3) FINISH: BEADBLAST ¢ IRRIDITE

CONTRACT NO.		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA			
DWN	MAL	4-6-83	REEL HUB		
ENGR					
CHK					
PROD					
APVD		SIZE B	CODE IDENT NO.	DRAWING NO. A-3417-014	
APVD		SCALE			SHEET

AP 26383A



NOTES:

1) MAT'L: ALUM. 6061-T6
2) FINISH: IRRIDITE
3) MAKE TIGHT SLIP FIT

CONTRACT NO.		
DWN	MAL	4-6-83
ENGR		
CHK		
PROD		
APVD		
APVD		

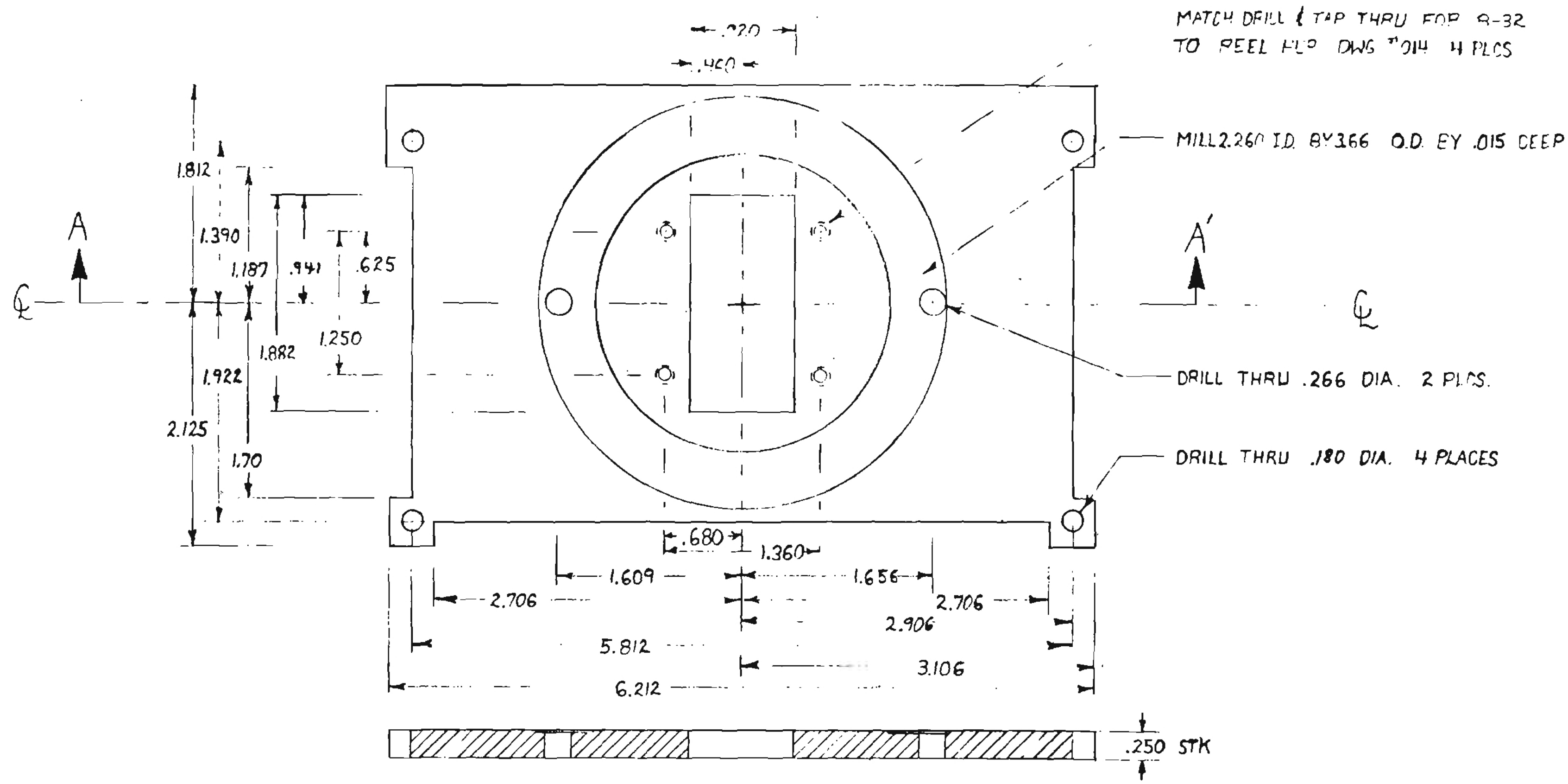
ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

GT EES

REEL

SIZE	CODE IDENT NO.	DRAWING NO.
B		A-3147-015

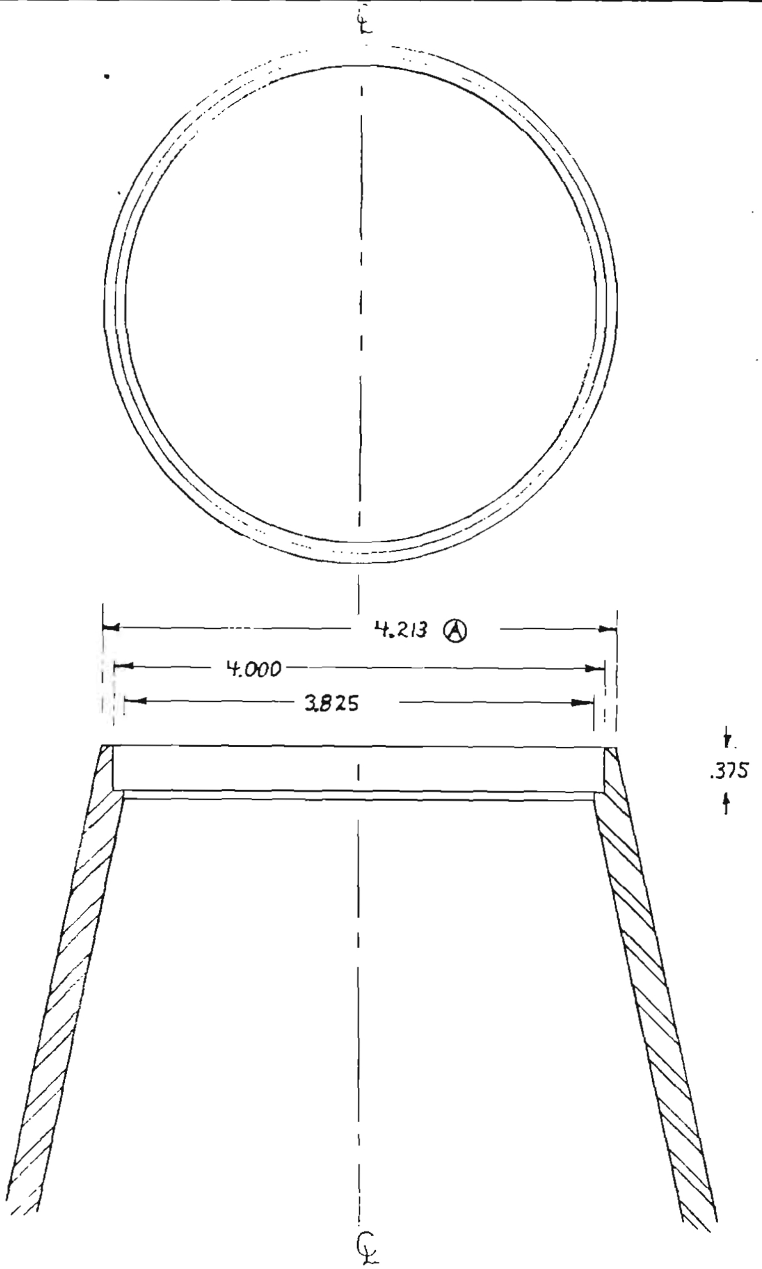
SCALE | | SHEET



SECTION A~A'

NOTES:
1) MAT'L ALUM. 6061-T6
2) TOLERANCES: .XXX ± .005
3) IRRIDITE

CONTRACT NO.		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA	
DWN	MAL	4-8-63	BASEPLATE
ENGR			
CHK			
PROD			
APVD		SIZE B	CODE IDENT NO.	DRAWING NO. 4-3447-016
APVD		SCALE FULL	SHEET



NOTES:
1) MAT'L RAYDOME PROVIDED
2) CUT OFF RAYDOME TILL DIA. REACHES DIMENSION (A)

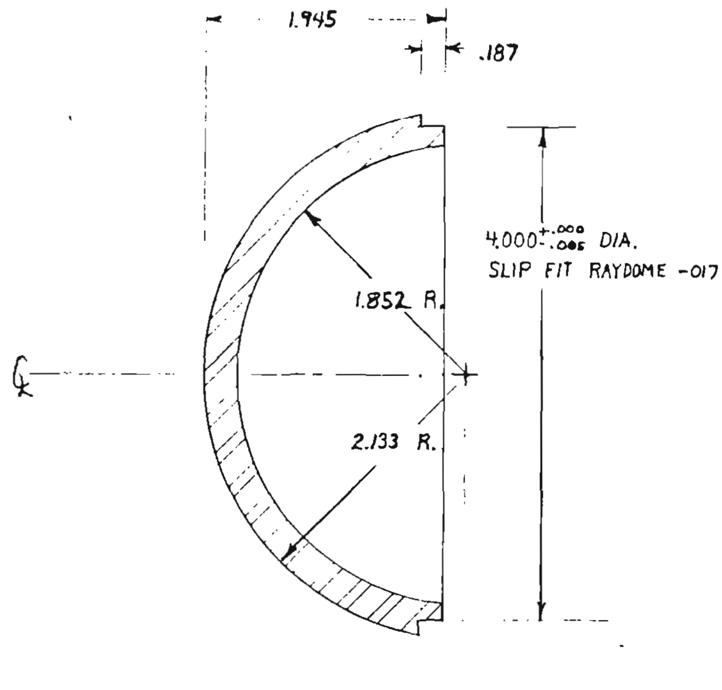
CONTRACT NO.	
DWN MAL	4-14-83
ENGR	
CHK	
PROD	
APVD	
APVD	

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

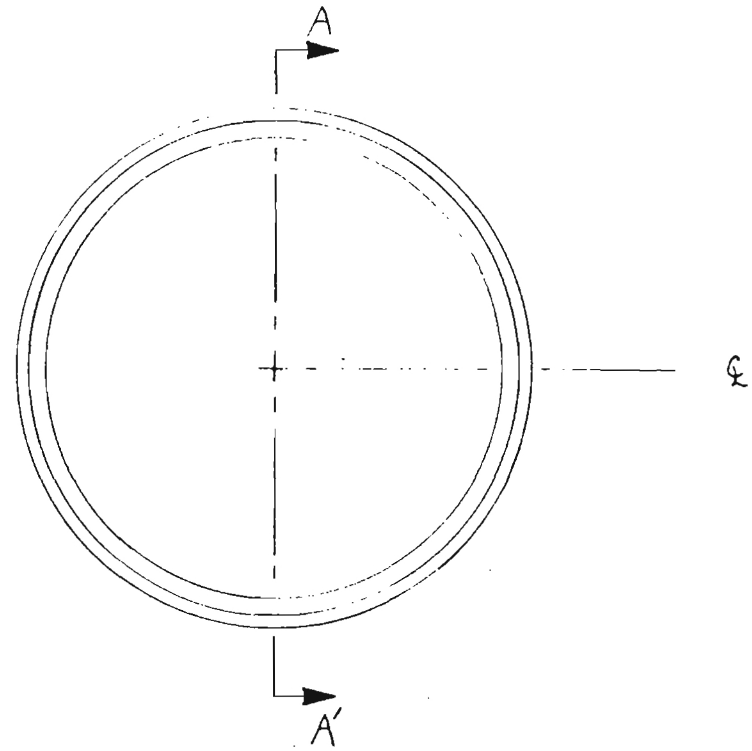
RADOME MODIFICATION

SIZE	CODE IDENT NO.	DRAWING NO.
B		A-3447-017

SCALE FULL | SHEET



SECTION A~A'



NOTES:

1) MAT'L PLEXIGLAS
2) POLISH FINISH

CONTRACT NO.		
DWN	MAL	4-15-83
ENGR		
CHK		
PROD		
APVD		
APVD		

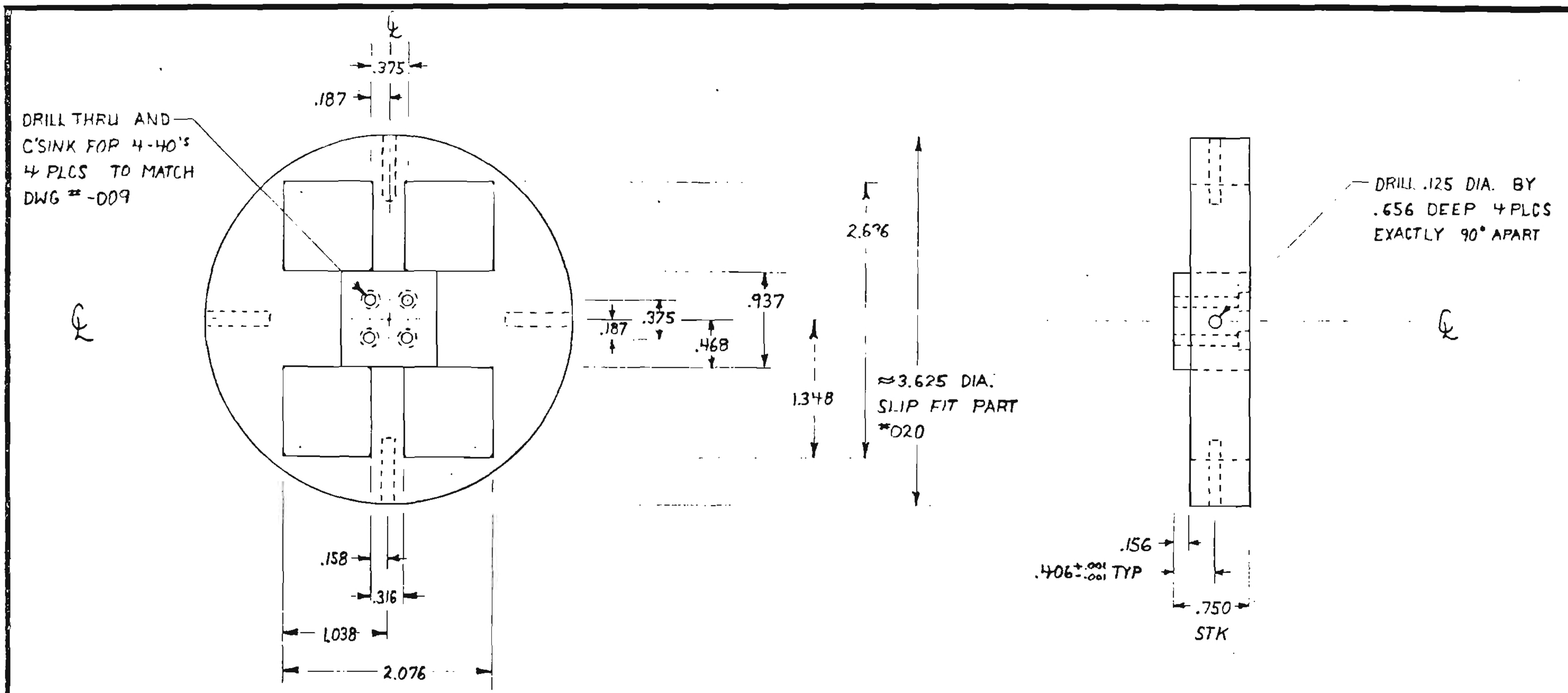
GT EES — ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY, ATLANTA, GEORGIA

IRDOME

SIZE	CODE IDENT NO.	DRAWING NO.
B		A-3447-018

SCALE FULL | SHEET

AF 26393A



NOTES:

1) MAT'L G-10 FIBERGLASS
2) TOLERANCES: .XXX ± .005 EXCEPT AS NOTED

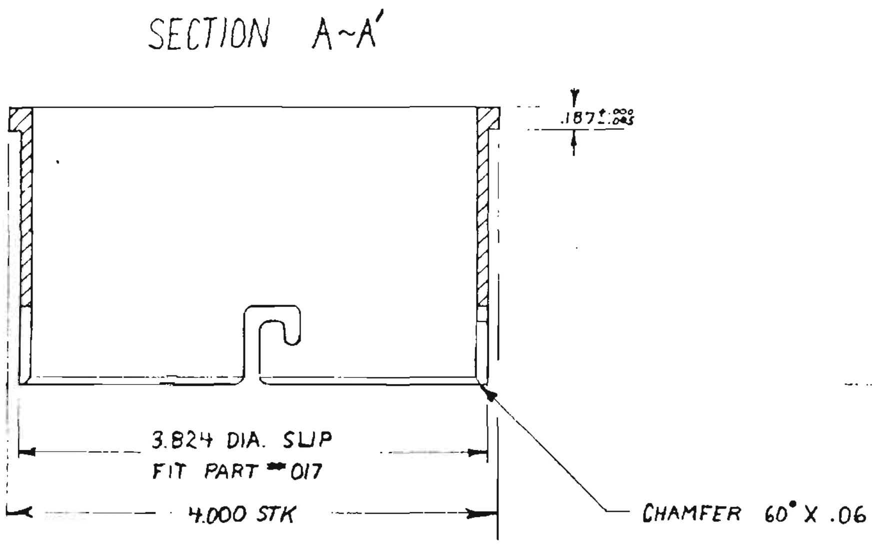
CONTRACT NO.		
DWN	MAL	4-19-83
ENGR		
CHK		
PROD		
APVD		
APVD		

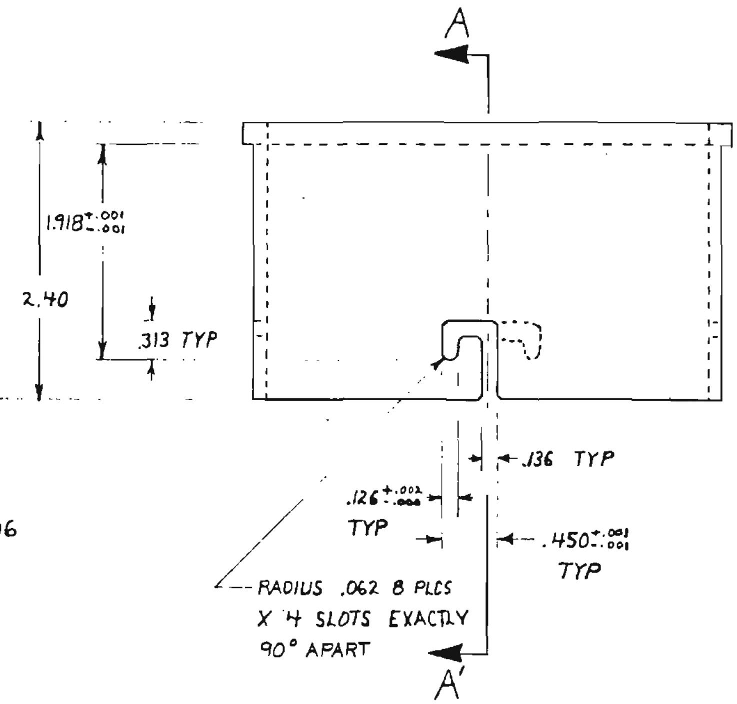
ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

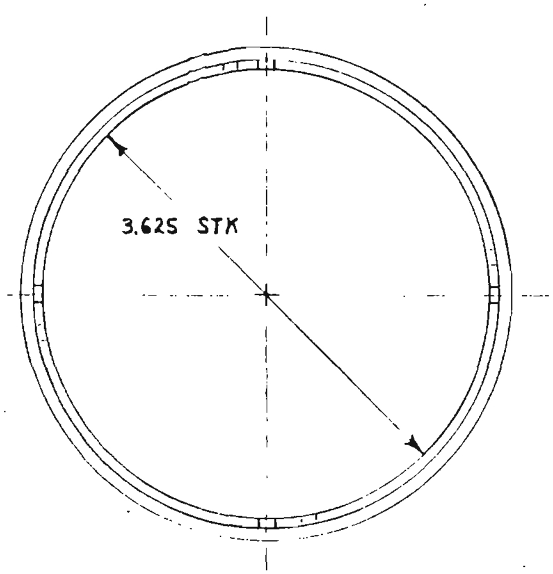
GIMBAL MOUNT

SIZE	CODE IDENT NO.	DRAWING NO.
B		A-3447-019

SCALE FULL | SHEET







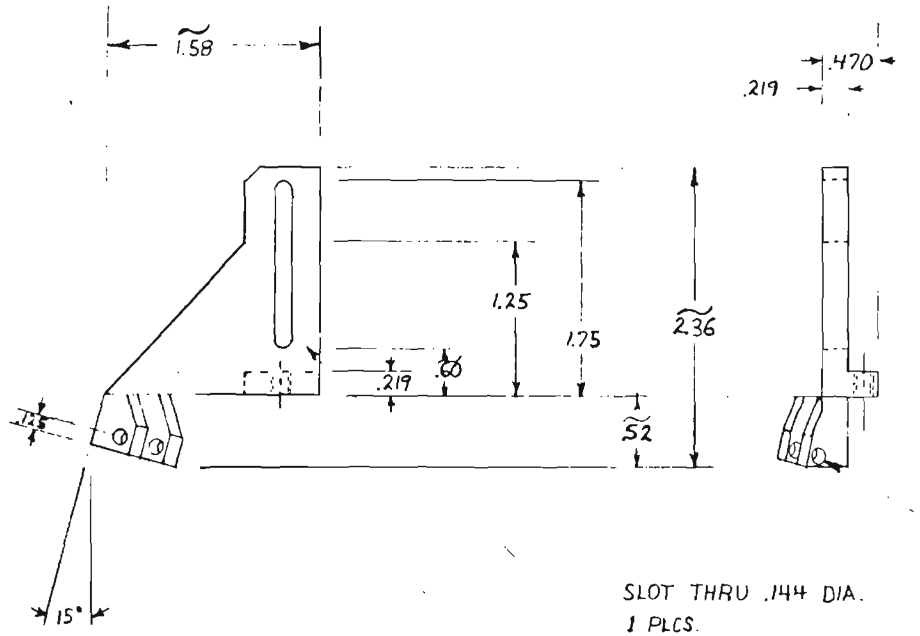
NOTE:

1) MAT'L 4"O.D. BY 3/16 WALL G-10 FIBERGLASS TUBE
2) SLOTS ARE SUCH THAT PART # 019 TURNS CLOCKWISE TO LOCK

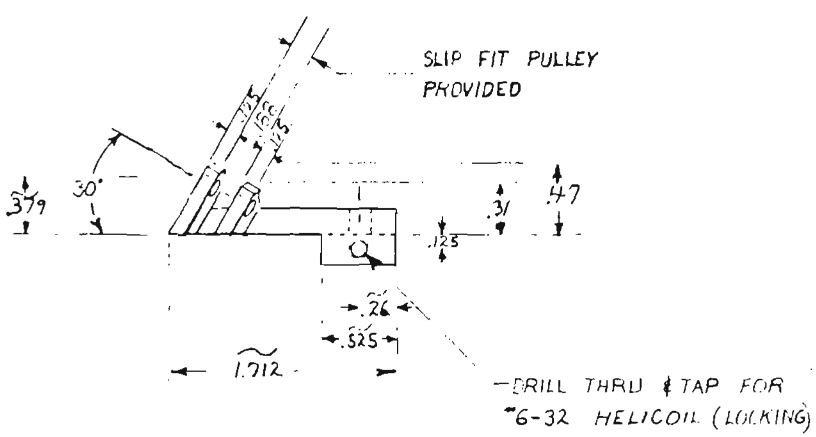
TOLERANCES:

.XXX ± .005
EXCEPT AS NOTED

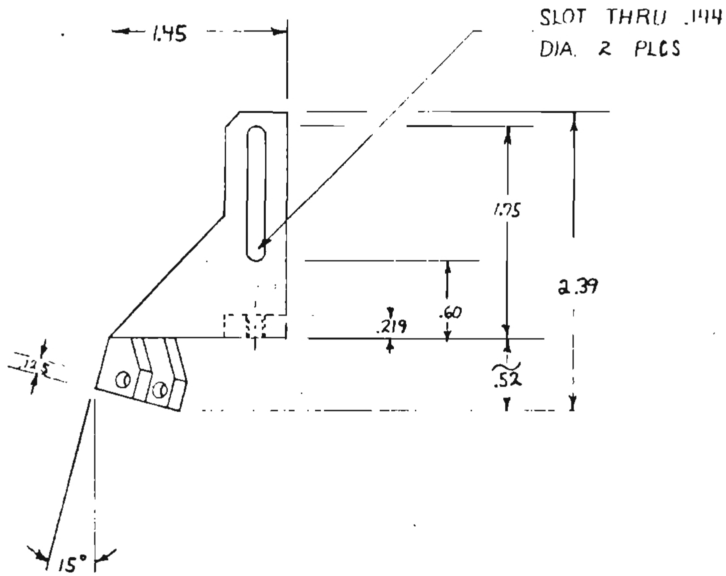
CONTRACT NO. A-3447		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA			
DWN	MAL	4-20-83	RADOME SLEEVE		
ENGR					
CHK					
PROD					
APVD			SIZE B	CODE IDENT NO.	DRAWING NO. A-3447-020
APVD			SCALE		SHEET

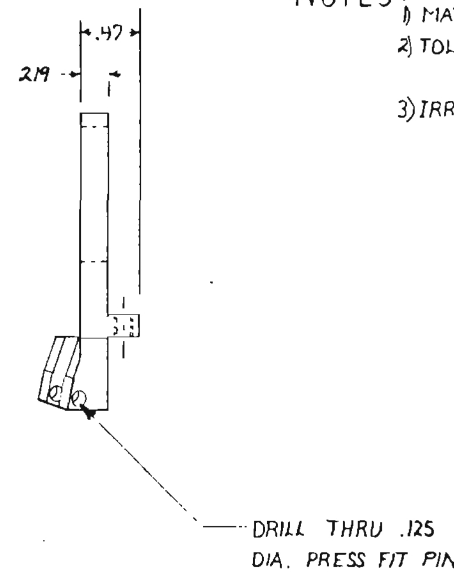


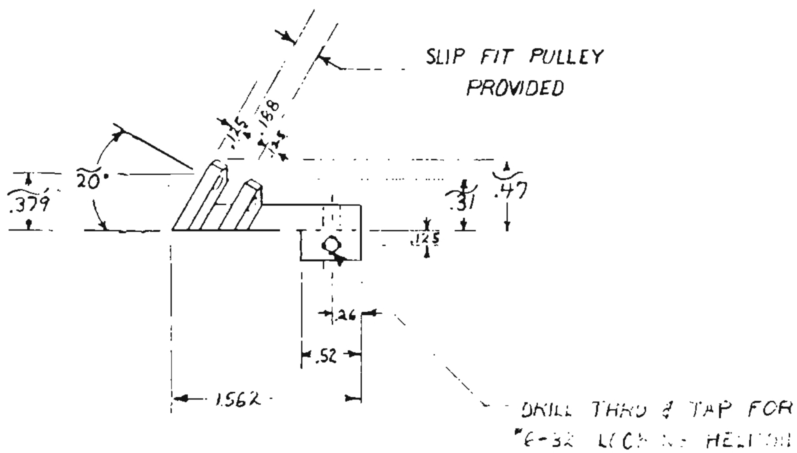
NOTES:
1) MAT'L ALUM. 6061-T6
2) TOLERANCES: .xxx ± .005
.xx ± .01



CONTRACT NO. A-3532-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA	
DWN MAL	5-10-83	SUM RT. STRING ADJUST	
ENGR			
CHK			
PROD			
APVD		SIZE B	CODE IDENT NO.
APVD		DRAWING NO. A-31147-002	
		SCALE FULL	SHEET





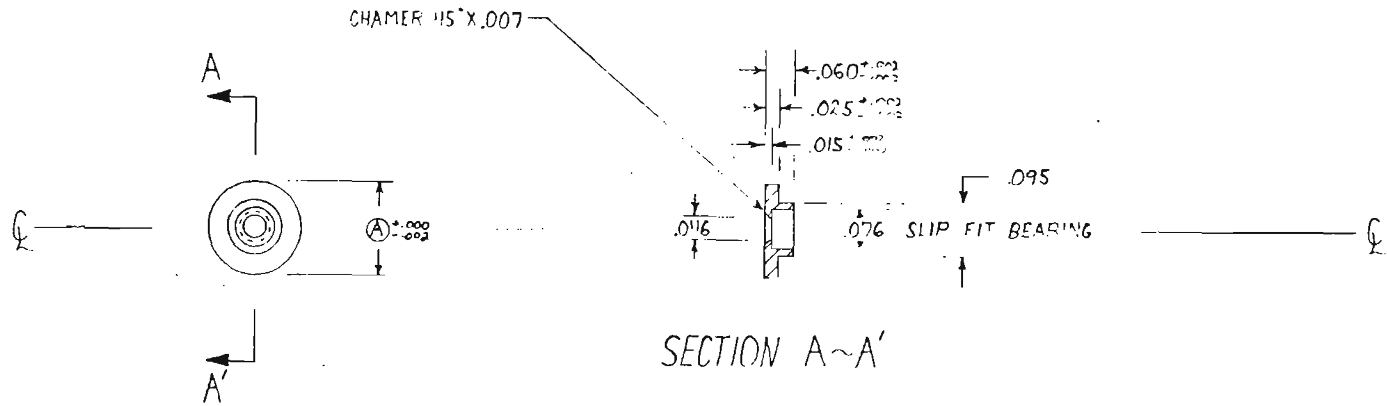


NOTES:

1) MAT'L ALUM. 6061-T6
2) TOLERANCES : .XXX ± .005
.XX ± .01
3) IRRIDITE

CONTRACT NO. A-3532-000	ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA
DWN MAL 5-11-83	AZ. LT. STRING ADJUST
ENGR	
CHK	
PROD	
APVD	SIZE B / CODE IDENT NO. / DRAWING NO. A-3447-023
APVD	SCALE / SHEET

AF 26393A

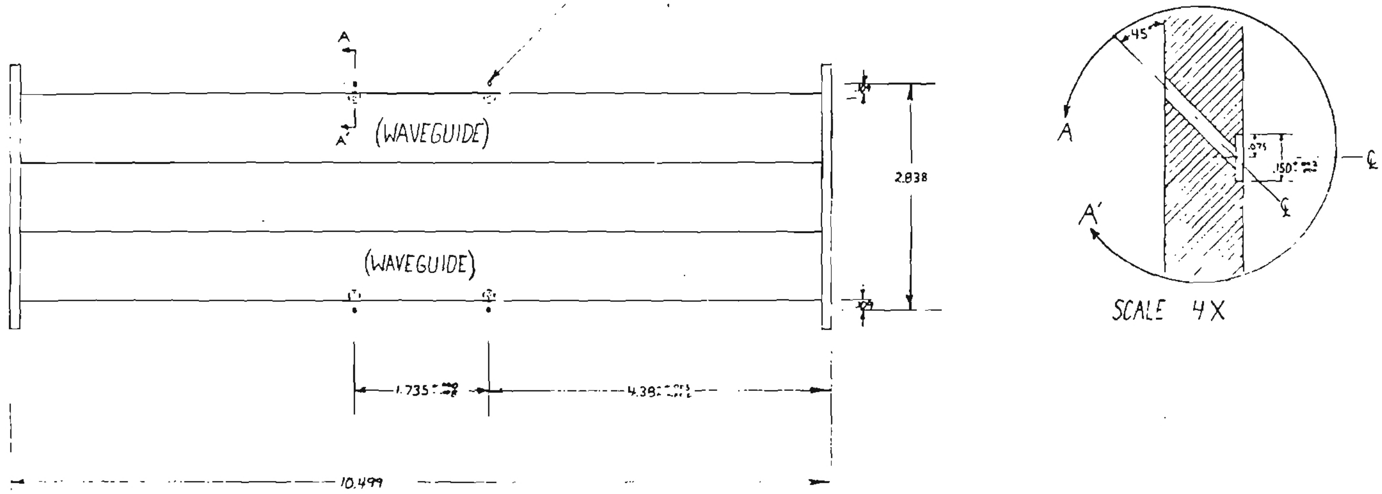


NOTES:

1) MAT'L ALUM.
2) DIMENSIONS Ⓐ .192 , .193 , .195 , .196
3) TOLERANCES: .XXX ± .005 EXCEPT AS NOTED
4) IRRIDITE FINISH

CONTRACT NO. A-3532-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA
DWN MAL	5-23-83	BEARING CUP
ENGR		
CHK		
PROD		
APVD		SIZE B / CODE IDENT NO. / DRAWING NO. A-3447-024
APVD		SCALE 4X / SHEET

REFERENCE WAVEGUIDE, DRILL THRU AT 45° TOWARD ANTENNAE EDGE .046 DIA, THEN C'BORE OTHER SIDE .190 DIA BY .025 DEEP AT 90°, CENTER C'BORE .007 TOWARD ANTENNAE CENTER



APPLICATION		
QTY REQD	NEXT ASSY	USED ON

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVED

ITEM OR FIND NO.	QTY REQD		NOMENCLATURE OR DESCRIPTION	MATL SPEC AND SIZE OR COMPONENT VALUE	IDENTIFYING OR PART NO.	CODE IDENT.

PARTS LIST

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED
TOLERANCES
3 PLACE DECIMALS ± .005
2 PLACE DECIMALS ±
1 PLACE DECIMAL ±
EXCEPT AS NOTED
FRACTIONS ± ANGLES ± 0°30'
MAX SURFACE ROUGHNESS 125 ALL MACHINED SURFACES EXCEPT AS NOTED
BREAK SHARP EDGES AND CORNERS .010 MAX
FINISH

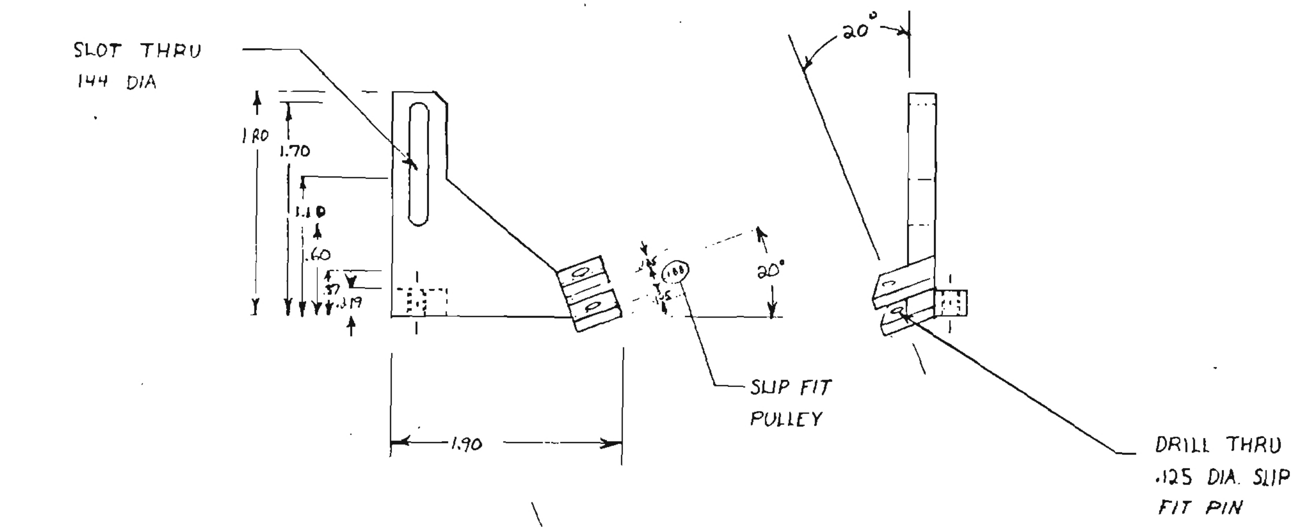
CONTRACT NO.
DWN MAL 5-17-83
ENGR
CHK
PROD
APVD
APVD

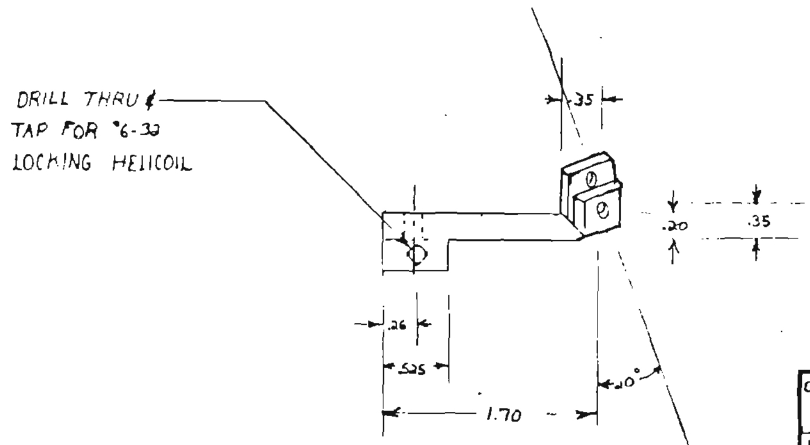
EES ENGINEERING EXPERIMENT STATION of the GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

ANTENNAE MODIFICATION

SIZE C | CODE IDENT NO. | DRAWING NO. A-3447-025 | REV
SCALE FULL EXCEPT AS NOTED | SHEET

AF 26393A

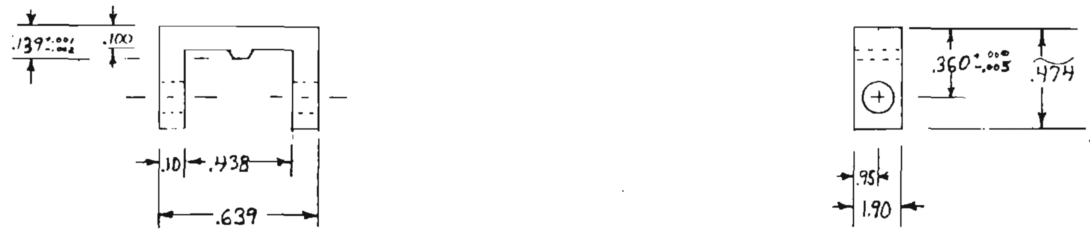




NOTES:

1) MAT'L ALUM. 6061-T6
2) TOLERANCES .XXX ± .005
.XX ± .010
3) ROUND CORNERS
4) IRRIDITE FINISH

CONTRACT NO. A-3532-000	ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA
DWN MAL 6-7-83	SUM LT. STRING ADJUST
ENGR	
CHK	
PROD	
APVD	SIZE B · CODE IDENT NO. · DRAWING NO. A-3447-026
APVD	SCALE FULL · SHEET



NOTES:
1) MAT'L TEFLON
2) TOLERANCES : .XXX ± .005
EXCEPT AS NOTED .XX ± .010

CONTRACT NO.		
DWN	MAL	6-7-83
ENGR		
CHK		
PROD		
APVD		
APVD		

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ATLANTA, GEORGIA

STRING GUIDE

SIZE	CODE IDENT NO.	DRAWING NO.
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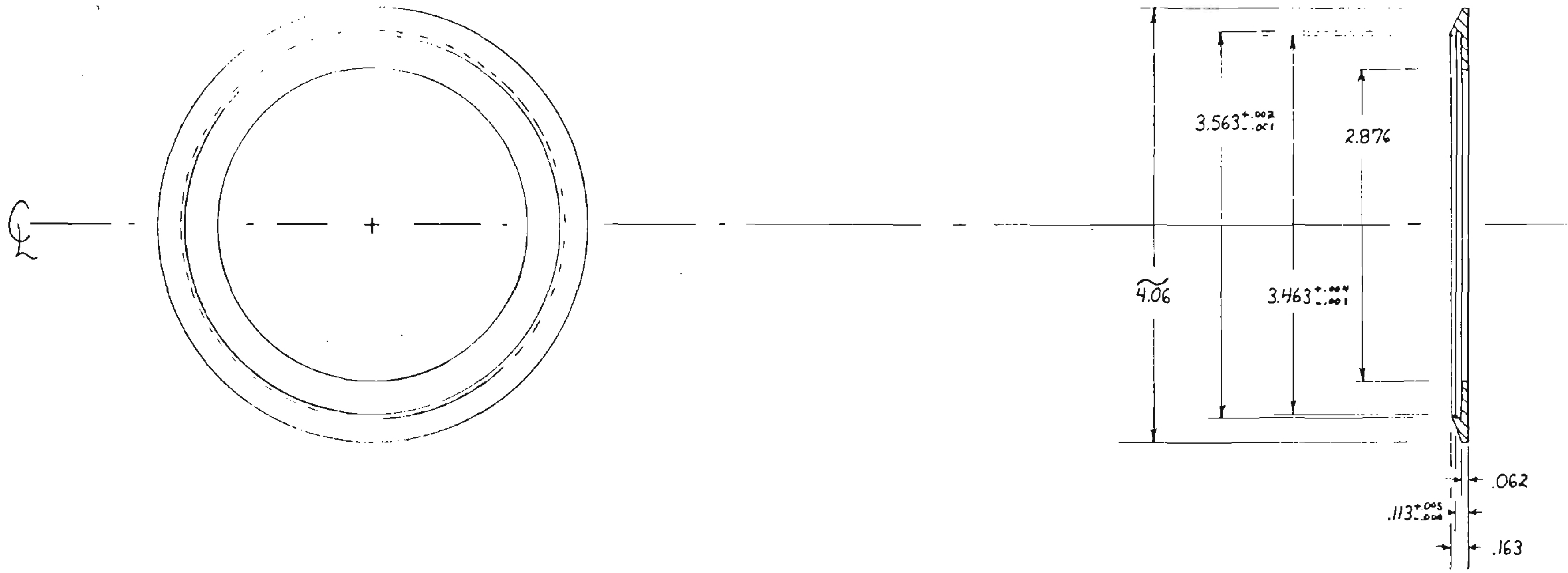
SCALE 2X		SHEET



NOTES:
1) MAT'L POLYETHELENE
2) TOLERANCES : .XXX ± .005
.XX ± .010
EXCEPT AS NOTED

CONTRACT NO. A-3532-000		
DWN	MAL	6-16-83
ENGR		
CHK		
PROD		
APVD		
APVD		

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REEL CUP

SIZE	CODE IDENT NO.	DRAWING NO.
B		A-3447-028
SCALE F/11		SHEET

LIBRARY DOES NOT HAVE

Cost Performance Reports #1, #2, #5, #6, #8

A-3532

COST PERFORMANCE REPORT #3

IRAG Hardware Development
Georgia Tech Project A-3532

Joe M. Newton
David C. Rady

Report Period
June 1 through June 31, 1983

Contract #DAAH01-83-D-A013
Delivery Order #10

Effective Date: 5 May 1983
Expiration Date: 30 September 1983

Prepared for

U. S. Army Missile Command
Advanced Sensors Directorate
Redstone Arsenal, Alabama 35898

Prepared by

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

WORK PERFORMED IN THIS WORK PERIOD

During this work period all mechanical and electrical work was completed for the modifications which were being done to the IHAWK seeker and radome. The modified equipment was returned to the Redstone Arsenal for further evaluations.

The results of the electrical radome tests are shown in Tables 1 through 3. A preliminary evaluation of these data indicates that the presence of the IR seeker does not cause an increase in the degradation of the boresight above that which is caused by the tip of the radome being removed. In addition, these tests show that for seeker pointing angles greater than about 15 degrees off the nose of the radome, no performance decrease occurs due to the presence of the modification in the radome nose. This is logical since the beam from the seeker antenna does not pass through this modified area when its "look angle" is larger than 15 degrees.

WORK TO BE PERFORMED DURING THE NEXT WORK PERIOD

Support will be given to the testing of the IRAG hardware in the RFSS in Huntsville on a "as needed basis".

PROBLEMS ENCOUNTERED DURING THIS WORK PERIOD

No problems were encountered during this report period and none are expected during the forthcoming period.

COST INFORMATION

The following charges have been incurred against the contract during this report period.

Personal Services (PS)	$ 3,850.60
Materials and supplies	514.18
Travel	290.75
Fringe Benefits	290.58
Overhead	2,334.56
TOTAL	$ 7,280.67

The current financial status of the contract is as follows:

NONMENCLATURE	BUDGET	EXPENDED	FREE BALANCE
Personal Services	$ 24,015.00	$ 9,468.53	$ 14,546.47
Material & Supplies	1,098.00	514.18	218.28
Travel	3,030.00	513.76	2,516.24
Fringe Benefits	5,043.00	1,252.20	3,790.80
Overhead	15,664.00	5,545.37	10,118.63
TOTAL	$ 48,850.00	$ 17,294.04	$ 31.190.42

Table 1. Null Shift in Difference Patterns

Unmodified Radome

AZ \ EL	0	5	10	15	20	30
0	0 0	-0.1 0.3	-0.1 0.4	-0.1 0.4	-0.1 0.3	-0.1 0.5
5	0.2 0.1	0.1 0.4	0.3 0.4	0 0.4		
10	0.5 0.2	0.3 0.5	0.5 0.6	-0.1 0.5	0.2 0.1	-0.2 0.1
15	-0.2 0.3	-0.2 0.5	0.4 0.3	-0.2 0.7		
20	-0.1 0.2		0.3 0.1		0.1 0.2	-0.2 0.2
30	-0.5 0.2		0.2 0.1		0.3 0.3	-0.1 0.4

Note: Δ_{AZ} listed first

Table 2. Null Shifts in Difference Patterns

Modified Radome

AZ \ EL	0	5	10	15	20	30
0	0.3	0.1	0	-0.1	-0.1	0.5
	0.4	1.0	-0.3	0.6	0.4	0.3
5	0	-0.3	0	0.3		
	0.1	0.2	-0.2	0.8		
10	-0.3	-0.2	0	-0.2	0.2	-0.1
	0.2	-0.2	0.3	1.0	0.1	0.1
15	0	0.1	-1.3	0.1		
	0	0.2	0.4	0.9		
20	-0.2		0.5		0.1	-0.3
	0.1		0.1		0.2	0.2
30	-0.5		-0.1		0.1	-0.4
	0.1		0.1		0.3	0.4

Note: Δ_{AZ} listed first

Table 3. Null Shifts in Difference Patterns

Modified Radome with IR Seeker Aseembly

AZ \ EL	0	5	10	15	20	30
0	0.4	0.2	0	-0.5	-0.1	-0.1
	0.2	1.5	0.1	0.1	0.4	0.8
5	1.2	0.6	-0.1	-0.3		
	0.1	1.3	0	0.3		
10	-0.3	-0.3	0.1	0	0.2	-0.1
	0.3	0.5	0.3	0.4	0.1	0.1
15	0.1	-0.1	-0.8	-0.6		
	-0.2	0.6	0.3	0.9		
20	-0.2		0.5		0.1	-0.3
	-0.2		0.1		0.2	0.2
30	0		0.2		-0.1	-0.5
	0		0.1		0.3	0.4

Note: Δ_{AZ} listed first

A-3532

COST PERFORMANCE REPORT #4

IRAG Hardware Development
Georgia Tech Project A-3532

Joe M. Newton

Report Period
1 July 1983 through 31 July 1983

Contract #DAAH01-83-D-A013
Delivery Order #10

Effective Date: 5 May 1983
Expiration Date: 30 September 1983

Prepared for

U. S. Army Missile Command
Advanced Sensors Directorate
Redstone Arsenal, Alabama 35898

Prepared by

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

WORK PERFORMED IN THIS WORK PERIOD

No activity to report this work period.

WORK TO BE PERFORMED DURING THE NEXT WORK PERIOD

Support will be given to the testing of the IRAG hardware in the RFSS in Huntsville on an "as needed basis".

COST INFORMATION

The following charges have been incurred against the contract during this report period.

Personal Services (PS)	$	8.40
Materials and supplies		356.44
Travel		-0-
Fringe Benefits		-0-
Overhead		180.23
TOTAL	$	545.07

The current financial status of the contract is as follows:

NONMENCLATURE	BUDGET	EXPENDED	BALANCE
Personal Services	$ 24,015.00	$ 9,476.93	$ 14,538.07
Material & Supplies	1,098.00	870.62	173.38
Travel	3,030.00	513.76	2,516.24
Fringe Benefits	5,043.00	1,252.20	3,790.80
Overhead	15,664.00	5,725.60	9,938.40
TOTAL	$ 48,850.00	$ 17,839.11	$ 30,956.89

A-3532

COST PERFORMANCE REPORT #7

IRAG Hardware Development
Georgia Tech Project A-3532

Joe M. Newton

Report Period
August 1 through August 31, 1983

Contract #DAAH01-83-D-A013
Delivery Order #10

Effective Date: 5 May 1983
Expiration Date: 30 September 1983

Prepared for

U. S. Army Missile Command
Advanced Sensors Directorate
Redstone Arsenal, Alabama 35898

Prepared by

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

WORK PERFORMED IN THIS WORK PERIOD

No activity to report this work period.

WORK TO BE PERFORMED DURING THE NEXT WORK PERIOD

Support will be given to the testing of the IRAG hardware in the RFSS in Huntsville on a "as needed basis".

COST INFORMATION

The following charges have been incurred against the contract during this report period.

Personal Services (PS)	$	8.40
Materials and supplies		356.44
Travel		-0-
Fringe Benefits		-0-
Overhead		180.23
TOTAL	$	545.07

The current financial status of the contract is as follows:

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) IRAG Hardware Development		5. TYPE OF REPORT & PERIOD COVERED Final Report 5 May-30 Sept. 1983
		6. PERFORMING ORG. REPORT NUMBER A-3532
7. AUTHOR(s) Joe M. Newton, Michael Leon, Don Bagwell, Donal Gallentine, David Rady		8. CONTRACT OR GRANT NUMBER(s) DAA H01-83-D-A013 Delivery Order #10
9. PERFORMING ORGANIZATION NAME AND ADDRESS Georgia Tech Engineering Experiment Station Atlanta, GEorgia 30332		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ----
11. CONTROLLING OFFICE NAME AND ADDRESS U.S.Army Missile Command Advanced Sensors Directorate Redstone Arsenal, Alabama 35898		12. REPORT DATE 30 September 1983
		13. NUMBER OF PAGES 43
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Same as above		15. SECURITY CLASS. (of this report) Unclassifed
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Unlimited

18. SUPPLEMENTARY NOTES

N/A

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

IHAWK, IRAG, Radome, Dual-mode Seeker

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the results of a program to modify an IHAWK radome so that an IR seeker could be placed in the nose of the radome. The method by which this was accomplished and electrical modeling of the radome is presented.

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Unclassifed

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FINAL TECHNICAL REPORT

IRAG Hardware Development
Georgia Tech Project A-3532

Joe M. Newton
Michael Leon
Don Bagwell
Donal Gallentine
David Rady

Contract No. DAAH01-83-D-A013
Delivery Order #10

Effective Date: 5 May 1983
Expiration Date: 30 September 1983

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1.0 Introduction

The purpose of this program was to determine the mechanical methods whereby an IR seeker could be installed in the nose of an IHAWK radome. The basic approach taken was to place the IR seeker in the nose of the IHAWK radome and connect it mechanically to the RF seeker antenna via four Kelvar strings. Perfect tracking between the two antennas will exist if both antennas rotate about pivot points that are equal distances from each antenna. Perfect tracking between the two antennas implies that they are positioned in parallel planes and, consequently, form two sides of a rectangular box with the four strings forming the other four edges. Therefore, the lengths of the four strings will remain equal for all pointing directions. When the concept was reduced to operational hardware it was found that the IR antenna plane moved about a pivot point located closer to the antenna than that of the RF antenna. In this case the lengths of the four strings do not remain constant for all pointing directions. To resolve the problem a spring loaded string take-up reel was placed behind the RF antenna so that constant tension would be exerted on all strings. This allowed the string lengths to change but prevented them from becoming slack and affecting tracking performance.

An IHAWK RF antenna and radome was modified to include the modifications noted and electrical and mechanical tests were conducted at the RFSS in Huntsville, Alabama. These tests proved the mechanical integrity of the modified systems. Many hours of static testing and simulated target intercepts were conducted during this time without any major mechanical problems.

However, during electrical testing it was demonstrated that the IHAWK RF seeker could not perform its intercept function efficiently with the modified radome in place. Oscillations, in the missile guidance loop, were generated when the target crossed into the modified region of the radome. This problem was not anticipated since all input data, from the Army, indicated that the RF seeker did not track in the nose region during an intercept.

Theoretical radome calculations, done after the RFSS tests, show large boresight errors and error rates exist in the nose area. These calculations indicate that boresight error slopes greater than 100% are created when a five inch section of the radome nose is obstructed. This is thought to be substantially greater than the IHAWK seeker can tolerate, thus the oscillations. However, if the size of the obstruction is reduced to approximately 2 to 3 inches, a reasonable track might be achieved. This is subjective, however, since relatively large error slopes still exist.

2.0 Mechanical

The purpose of the mechanical effort was to mount a model infrared seeker, Dwg. #21 (see Appendix) in the front of an IHAWK missile radome. The IR circular disk model was required to track parallel to the IHAWK RF antenna up to 55^{o} in all directions.

The method used to accomplish tracking was demonstrated by a system model, provided by the Army. In this model four strings were used to control the movement of the IR seeker. Parallel tracking can be attained with four strings of equal length if the planes of the RF antenna and IR seeker pivot about points equal distance from the antenna surfaces. The main difficulty arises because the IHAWK antenna pivots about a point about three inches behind it. However, not enough space was available in front of the radome to accommodate the IR seeker's movement about a point matching the RF antenna's distance to its pivoting point. Therefore, the IR seeker was forced to pivot about a much closer point.

This difference, in pivoting distances, required the string lengths to change as the seeker tracked. A spring-loaded reel was used to make the necessary length changes in the strings. This reel, Dwg. #015, was mounted on the back side of the RF antenna in order to prevent radiation blockage to the antenna. Friction in the reel was found to limit tracking accuracy. Therefore, a "Reali-Slim" ball bearing, #KA025CPO, was installed between the reel and its hub, Dwg. #014, to reduce friction to a minimum.

The take-up reel is attached to the back of the RF antenna by means of a baseplate, Dwg. #016. Four bolts hold the reel to the baseplate which is sandwiched between the antenna and its gimbal mount. This effectively moved the RF antenna forward of its original mounting location by 1/4", the thickness of the baseplate.

Routing the strings from the reel through to the front of the RF antenna required the string to change direction by 90 degrees. To accomplish this, an Idler pulley, Stock Drive Products,#669-0084, was used to direct each string from the reel to a hole through the antenna. It was evident that more string adjustment was needed than could be achieved at the seeker end alone. However, string adjuster, Dwgs. #022, 023, 026, was added for each string in order to change the length of the string path on the back side of the RF antenna. It is these string adjusters located on the IHAWK RF antenna that made a second radome with access holes necessary.

The holes through the antenna were the determining factor in most of the dimensions for the seeker assembly. The IHAWK antenna is made of waveguide that cannot be punctured without making the antenna useless. Consequently, the only place to drill through the antenna was between the walls of adjacent waveguides. The two walls allow a hole of .046" dia. without breaking through into the waveguide. The holes also had to be drilled outside the two waveguides that run across the back of the antenna (see Dwg. #024). The final spacing of these four holes had to be duplicated on the seeker to attach the strings. It was this hole pattern that set the size of the IR seeker's mounting plate.

Wear on the strings as they worked back and forth through the holes in the antenna was a major cause of string failure. To combat this wear a ruby bearing was added on the front of each of the holes. Each bearing was secured in a bearing cup, Dwg. #024. The cup was crimped to hold the bearing in. The RF antenna was counter-bored .025" deep and the cup was glued in the counter-bore.

Radiation blockage to the antenna was kept to a minimum. This was done by making the IR seeker as small as the hole string pattern would allow. Fiberglass (grade G-10) was chosen because of its strength as the material for the seeker assembly. The IR gimbal, Dwg. #013, was the only part in the assembly not made of fiberglass.

Two radomes were necessary, one for tests and the other for string adjustment. This made it necessary to change radomes without affecting the string adjustment. Both radomes were modified, Dwg. #017, to accommodate the radome sleeve, Dwg. #020. The radome sleeve seats firmly in the modified radome from the front. This creates a removable support for the IR gimbal. The slots in the radome sleeve and the pins in the gimbal mount, Dwg. #019, allow easy positioning and removal of the seeker assembly. The seeker assembly is slipped into the radome without detaching the strings. The sleeve is then swapped from the one radome to the other.

The IR seeker mount plate was attached to the IR gimbal to allow the 55° freedom of movement. The IR gimbal was mounted in the front of the radome on the gimbal mounting plate set in the radome sleeve. The size of this assembly was minimized for the given string pattern. Tracking was accomplished by the four strings and the spring-loaded take-up reel. To insure parallel tracking, the strings are adjusted through access holes in the extra radome.

2.1 String Replacement Procedure

1) Remove IR dome: Push in the 3 dowel pins, located where the radome and IR dome meet,then pull IR dome straight forward.
2) Detach IR seeker from assembly from radome: Reach into the hole vacated by the IR dome and grasp the seeker mounting plate. Pull IR seeker forward 2/10 of an inch, then twist counterclockwise. The seeker will then be free to slide back into the radome.
3) Remove the radome: Turn the radome counterclockwise and pull forward. Once the radome clears the antenna catch the seeker assembly before it falls.
4) Remove the antenna: The semi-rigid coax coupling, from the local oscillator power divider to the sum and azimuth mixers must first be detached. The coax from the missile body to the power divider must also be disconnected. Once this is done, remove the four bolts that hold the antenna to the gimbal, and the antenna will fall free.
5) Remove take-up reel and spring: Take out the four bolts that secure the reel hub to the baseplate. Turn the reel and hub over. Pull the outside end of the spring from its slot to access the four string holes.
6) Replace string: The string must be one continuous strand allowing for a loop at one end. The hole through the ruby bearings matches the O.D. of the string. To thread the string through the antenna, loop a fine wire through the loop on the end of the string. Feed this wire through the bearing in the front of the antenna. Pull the string through the antenna, over the idler pulley and through the hole in the reel. Tie a large knot on the end of the string

inside the reel to keep it from pulling through the hole. Replace the spring and bolt the hub back on the baseplate. Mount the antenna on its gimbal and reconnect the three coax that were disconnected.

7) Attach the string to the IR seeker mounting plate: Feed the free end of the string through the square hole in the gimbal mount, Dwg. #019, then through the corresponding hole in the seeker mount plate. Leave this end free for now.

8) Mount the radome with access holes: Set the seeker assembly in the radome. Align the radome and turn clockwise to alignment marks on side of radome and missile body.

9) Mount the seeker assembly in the front of the radome: Slide the radome sleeve, Dwg. #020, into the front of the radome and align the marks. Make sure the strings are not twisted. Pull the assembly into the radome sleeve. Twist clockwise, then push in.

10) Secure string(s): (If just replacing one string) Pull replacement string until it is as tight as the three other strings. Knot the string where it comes through the seeker mount plate. (If replacing all four strings) Pull all four strings evenly, then mark and knot the strings where they emerge from the seeker mount plate.

11) Adjust string(s): Loosen bolt in slot of string adjuster, Dwgs. #022, 023, 026. Then loosen or tighten string by running out or in, respectively, the tapped screw on the adjuster. Also, a very small amount of adjustment can be attained by backing out or turning in the Allen head set screws on the seeker mount plate.

12) Replace the original radome: Repeat steps 3, 8, 9, then install IR dome and dowel pins.

3.0 Radome Modeling

3.1 General

The radome model used for the theoretical analysis was an approximation of the HAWK radome. The shape was taken to be a tangent ogive having the basic geometry defined in Figure 3.1; for the model used the values of the parameters are:

$$D = 13.46 \text{ in.}$$
$$L = 48.47 \text{ in.}$$
$$\Delta = 10.75 \text{ in.}$$
$$\delta = 0 \text{ in.}$$
$$d = 10.7 \text{ in.}$$

The monolithic wall was assumed to be E-glass with a dielectric constant of 4.4 and a loss tangent of .016. This resulted in higher boresight error (BSE) values than a previously used dielectric constant of 5.

The wall thickness specified for the radome was a prescription based on actual measurements of the wall. The measurements were approximated by least-squares analysis to form the following prescription:

$$\text{THK(inches)} = (0.282 + 0.0064\theta^2)$$

$$\text{COS}\left(\frac{\text{DIST}-34\cdot-4\theta}{34\cdot-4\theta}\right)(0.5 + 0.108\cdot \text{ABS}(\theta - 0.628)$$

where DIST = Station referenced to radome tip (inches)

θ = Radome circumferential angle from vertical (radians)

The radome was assumed to be symmetric about the vertical plane. The antenna was assumed to be vertically polarized with a cosine illumination function.

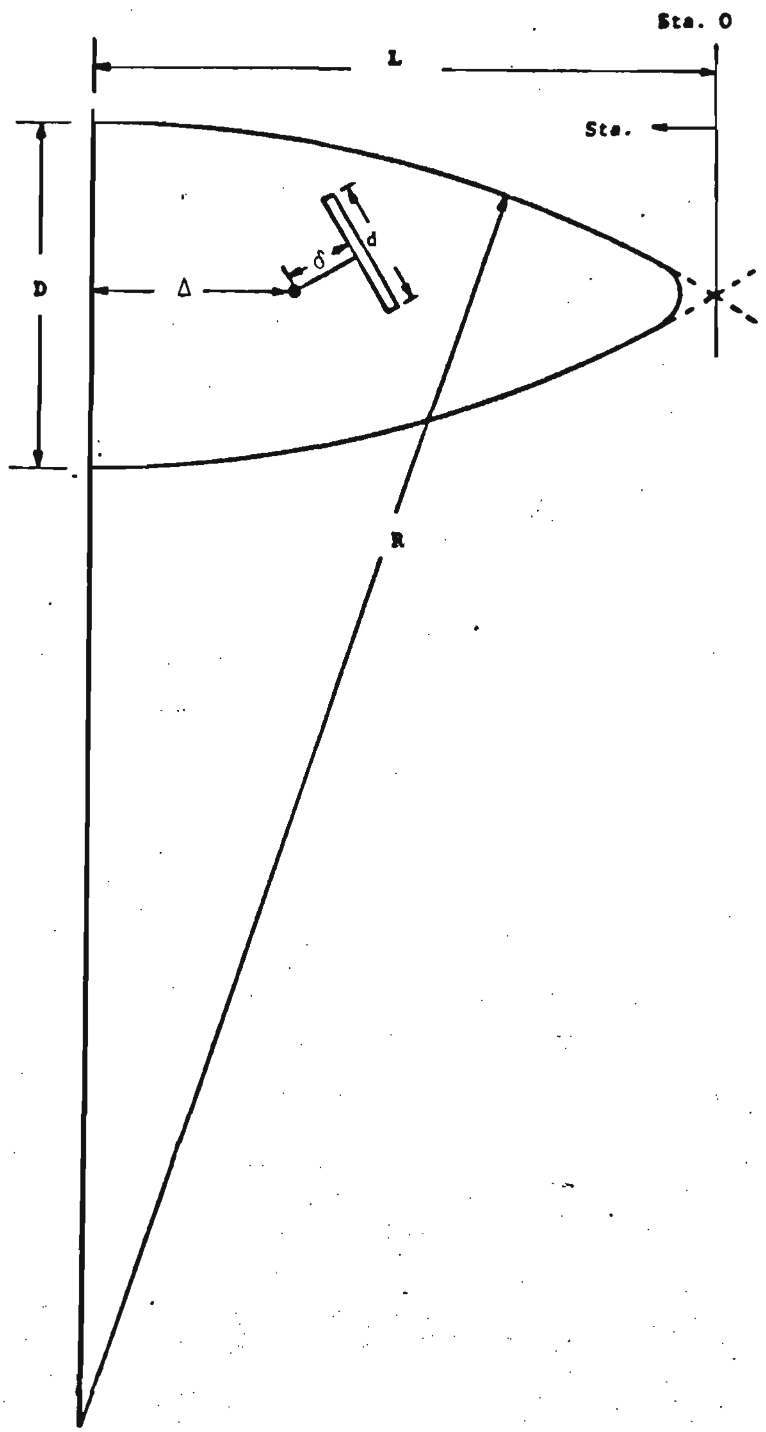


Figure 3.1. Geometry for Tangent Ogive Radome Performance Calculations.

3.2 Analysis

A physical optics (ray-tracing) program was used to model the interaction betwen the radome and the incoming wave. Radome blockages and apertures (apertures implying that the tip of the radome was removed) centered about the radome axis were simulated. The blockages and apertures modeled varied in diameter from 0 to 5 inches. The distance of the blockage or aperture from the antenna was determined from the tangent ogive geometry of the radome. If a real blockage extended closer to the antenna than this position then a larger effective blockage could be used.

The azimuth and elevation BSE's for azimuth and elevation principle planes were calculated for angles off-axis of from 0 to 15 degrees were calculated. The BSE's calculated for blockage are seen in Figures 3.2 and 3.3. The additional BSE errors induced by adding blockage were 0.0 for zero offset angle, rising to a maximum at 4.0 degrees, and then returning to 0.0 again at 14.0 degrees. Direct calculations show that the 4.0 degree offset is the approximate position where the "shadow" of the blockage is centered on half the antenna and that for offsets greater than 15 degrees the blockage shadow no longer intercepts the antenna. For blockages smaller than 5 inches the return of the BSE curve with blockage to the BSE curve with no blockage occurs at a smaller offset angle. The BSE slopes for different blockages are plotted in Figures 3.4 and 3.5. The slopes approach 100% $\left(\frac{\text{Change Error(Deg)}}{\text{Change Angle(Deg)}} \times 100\right)$ for a five inch blockage for both the azimuth and elevation scans.

The BSE curves for different apertures in the radome are plotted in Figures 3.6 and 3.7. The BSE curves for apertures have larger peak BSE values than the curves for blockage. The direction of the additional BSE added by the apertures is the same (negative) for both the azimuth and elevation scans. This

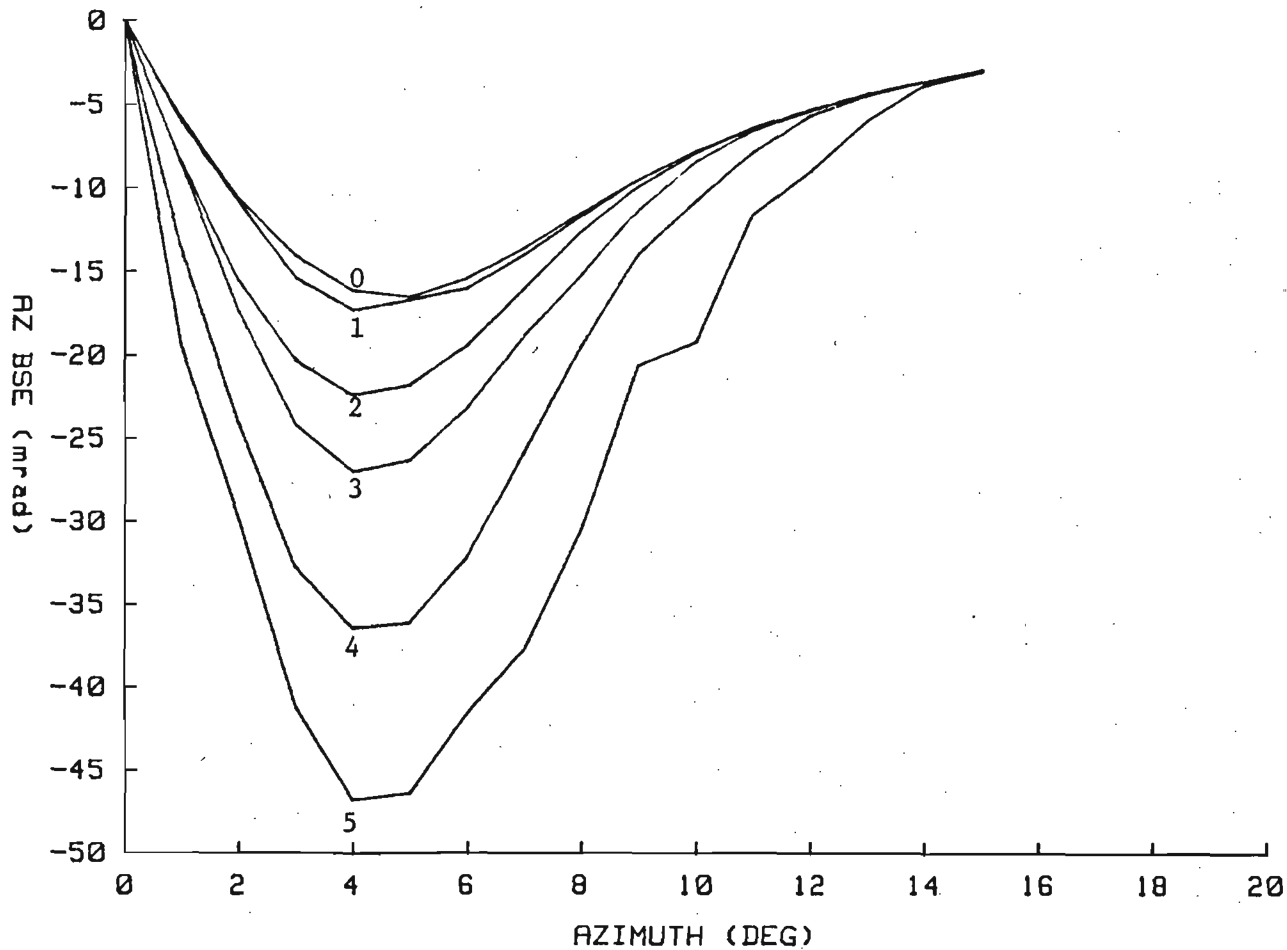


Figure 3.2. Azimuth BSE as a function of azimuth angle for blockages of 0 to 5 inches in diameter.

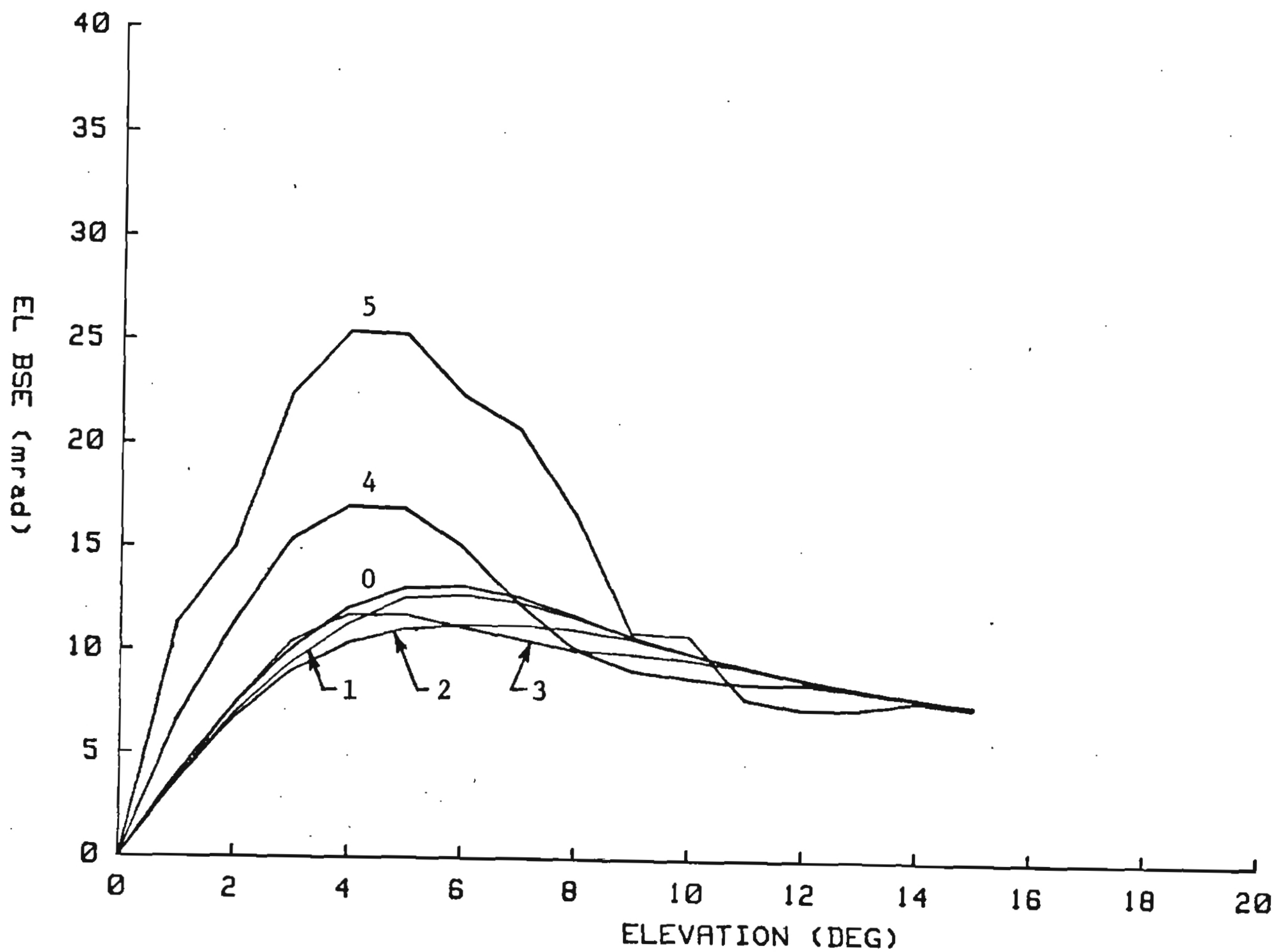


Figure 3.3. Elevation BSE as a function of elevation angle for blockages of 0 to 5 inches in diameter.

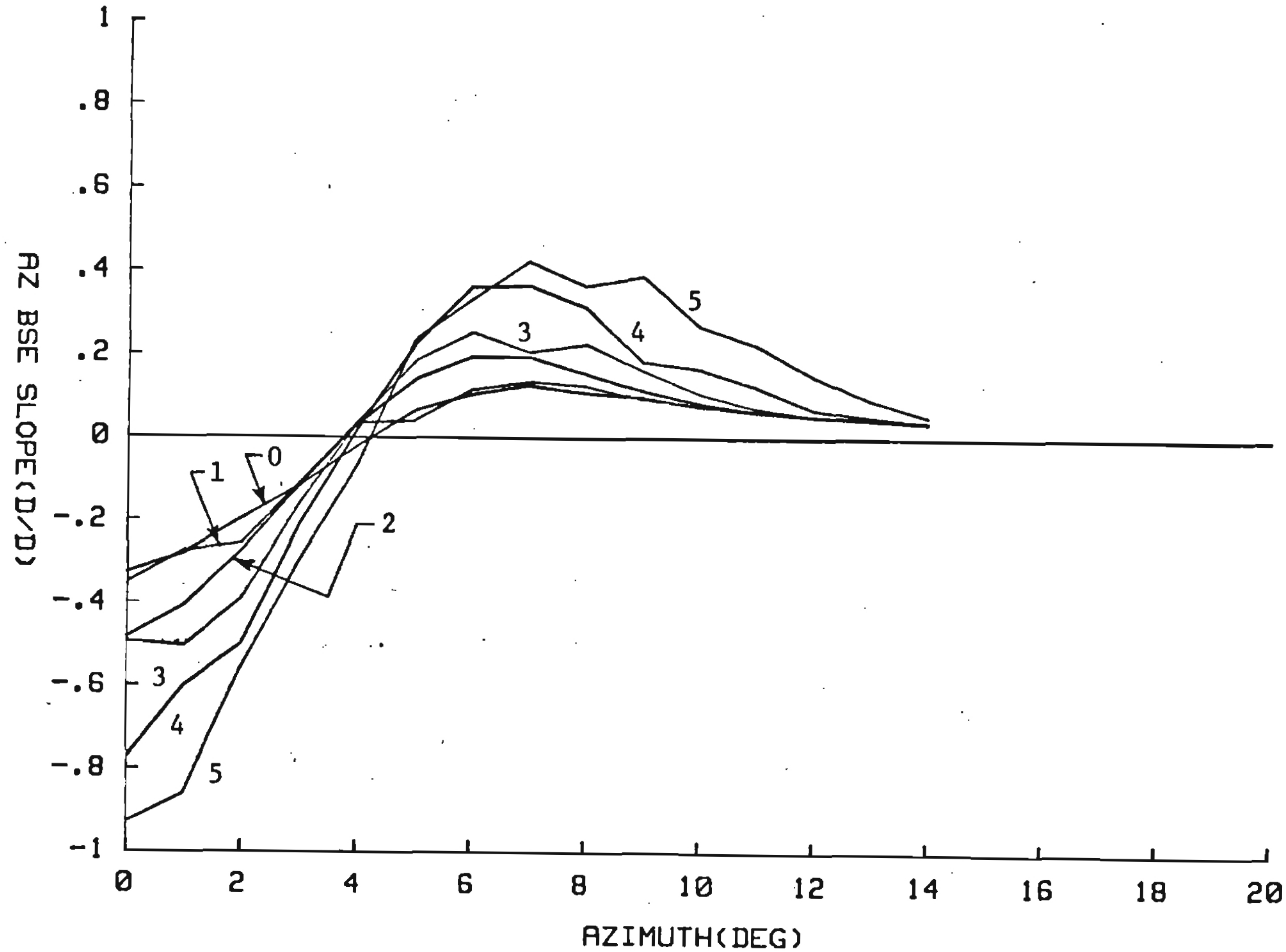


Figure 3.4. Azimuth BSE slope as a function of azimuth angle for blockages of 0 to 5 inches in diameter.

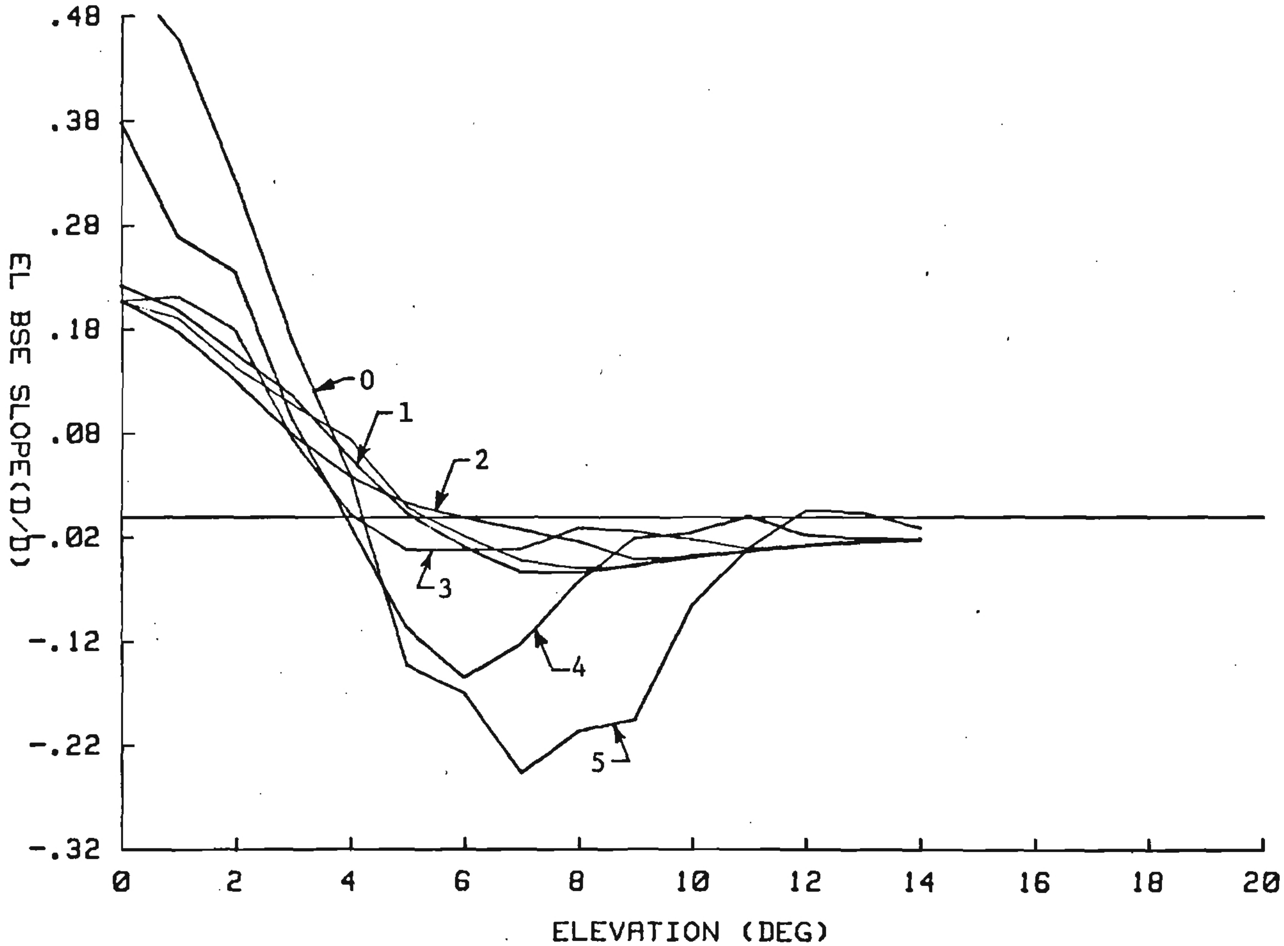


Figure 3.5. Elevation BSE slope as a function of elevation angle for blockages of 0 to 5 inches in diameter.

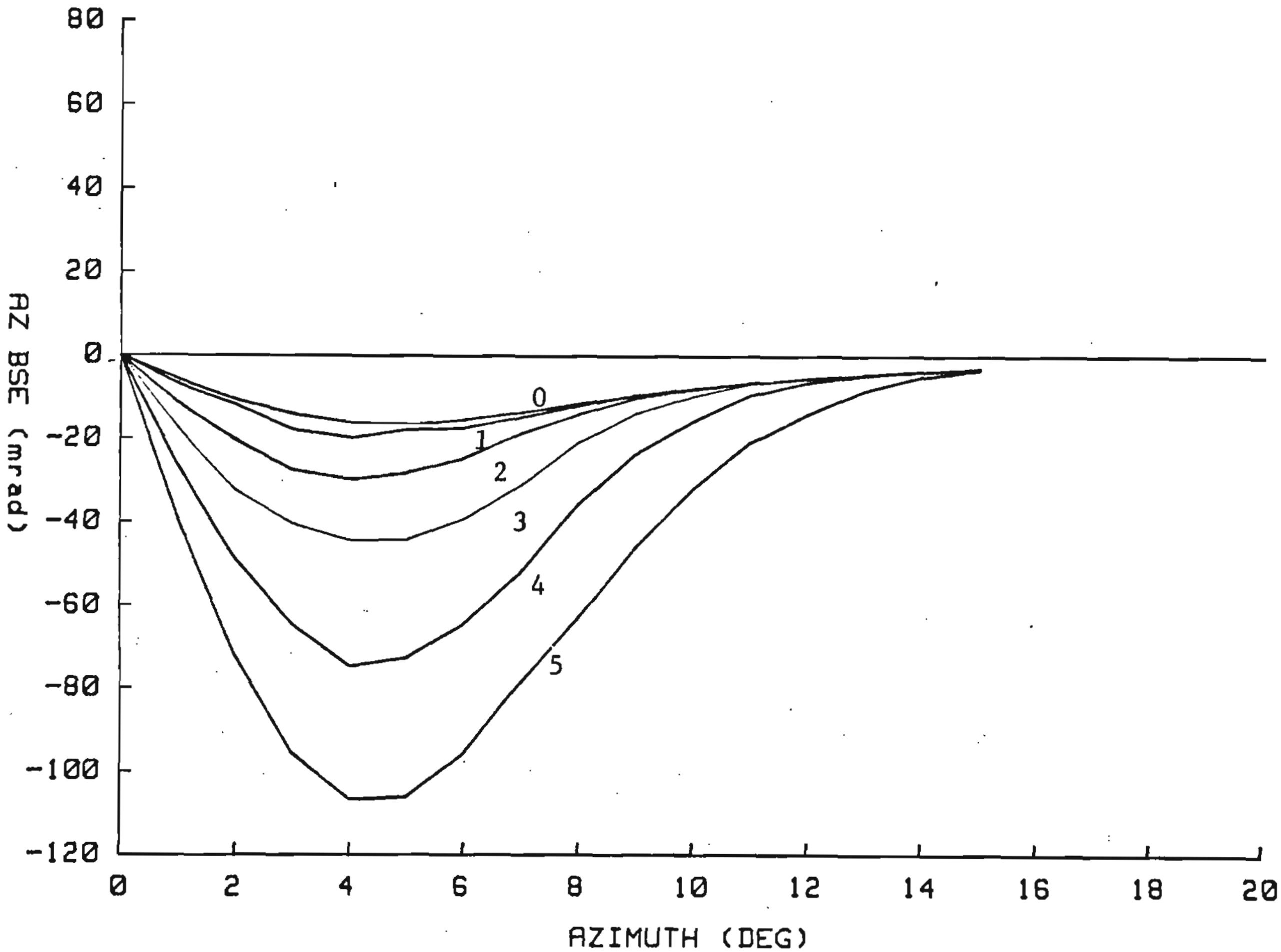


Figure 3.6. Azimuth BSE as a function of azimuth angle for apertures of 0 to 5 inches in diameter.

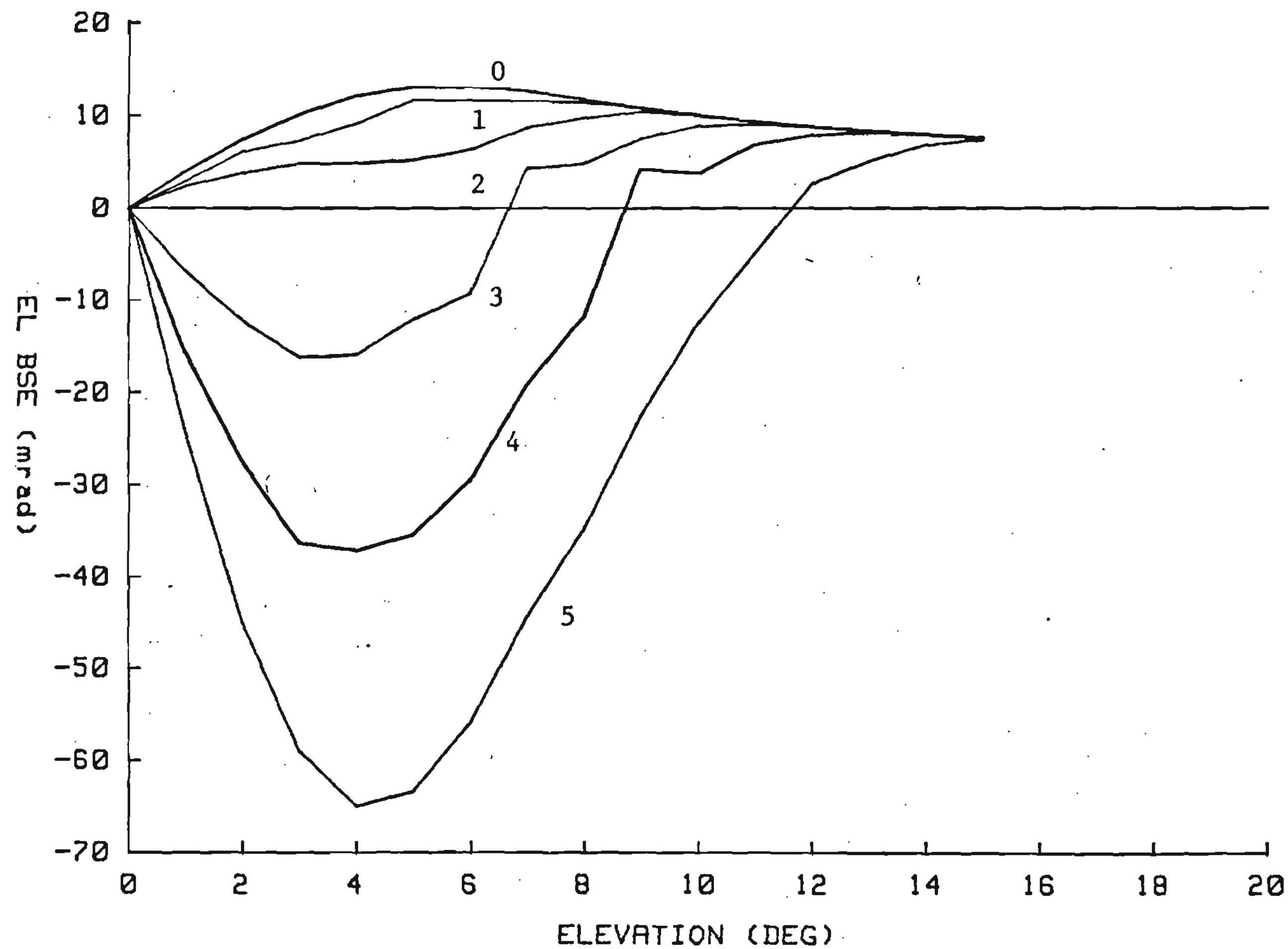


Figure 3.7. Elevation BSE as a function of elevation angle for apertures of 0 to 5 inches in diameter.

contrasts with the BSE's induced by blockage in which they were in the same direction as the original BSE's (no blockage), and the original BSE's were in opposite directions for azimuth and elevation scans. The BSE slopes for apertures in the radome are plotted in Figures 3.8 and 3.9. The slopes get as large as 200 percent for a 5 inch blockage.

3.3 Results and Conclusions

In all of the boresight error and boresight error slope plots the blockages and apertures of 4 or 5 inches lead to large values for both the boresight error and the boresight error slope. Since the effect of blockage obviously depends on the area of the blockage, this area should be kept to a minimum to reduce errors. The blockages of 4 and 5 inches in diameter have a much larger error slope than the rest. The large errors for an aperture in the radome imply that the rays passing through the aperture are nearly 180 degrees out of phase with those coming through the radome. Any attempt to pass radiation through the desired IR seeker location should make sure that the electrical thickness of the modified region is approximately the same as that of the radome before the modification.

The oscillations observed in the flight simulation are probably due to the high BSE slopes. The large slopes calculated above are above the design limits of the seeker tracking mechanism and electronics. As the missile starts to track through the nose the blockage shadow falls on the antenna and the large BSE's should cause the seeker to over-react in its movement and enter the oscillatory phase. Reducing the BSE values and slopes is the prefered method of minimizing the oscillations. A possible alternative is to store a BSE map in an onboard digital computer. The main disadvantages to this method are that the BSE's are hard to measure accurately and the actual BSE's would

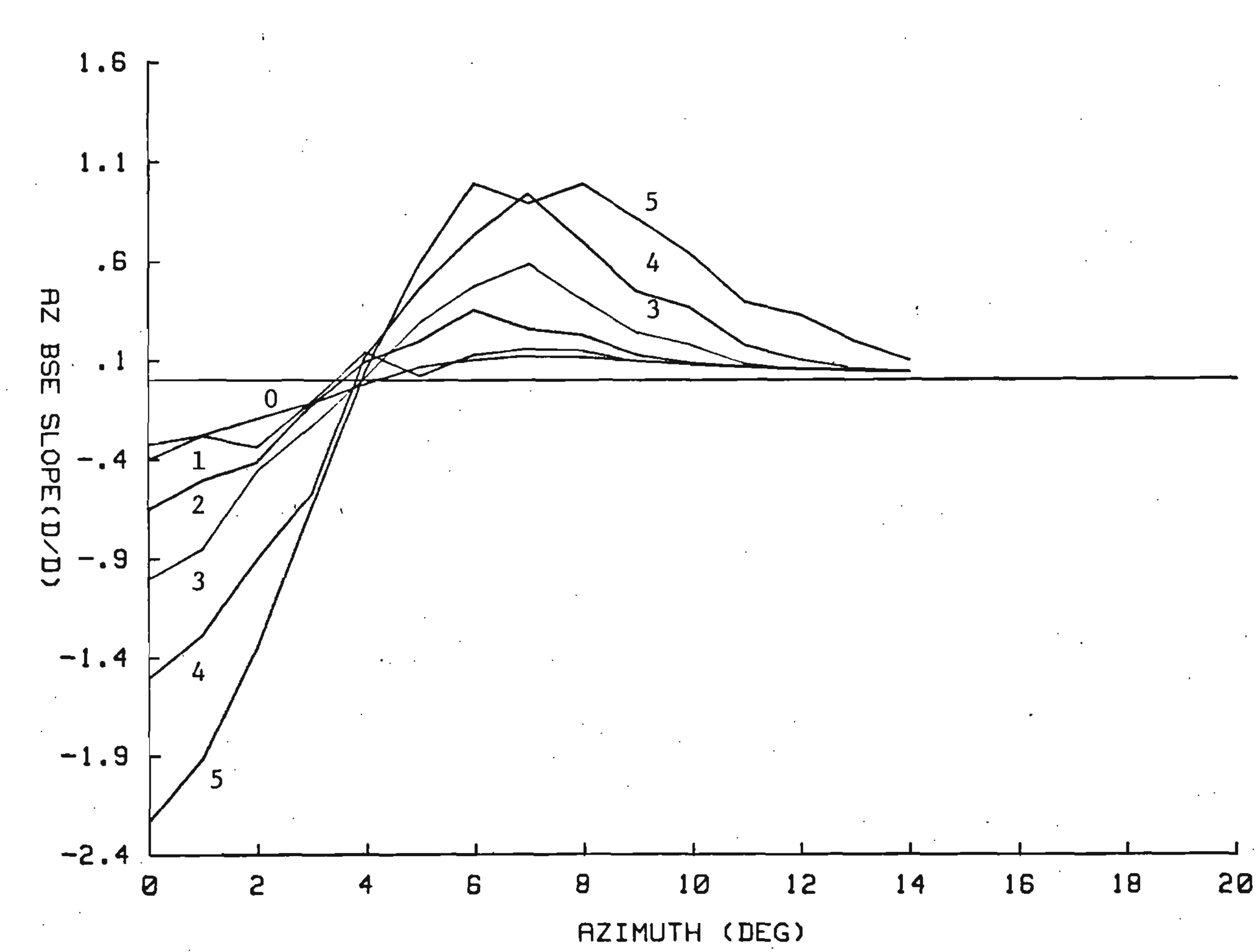


Figure 3.8. Azimuth BSE slope as a function of azimuth angle for apertures of 0 to 5 inches in diameter.

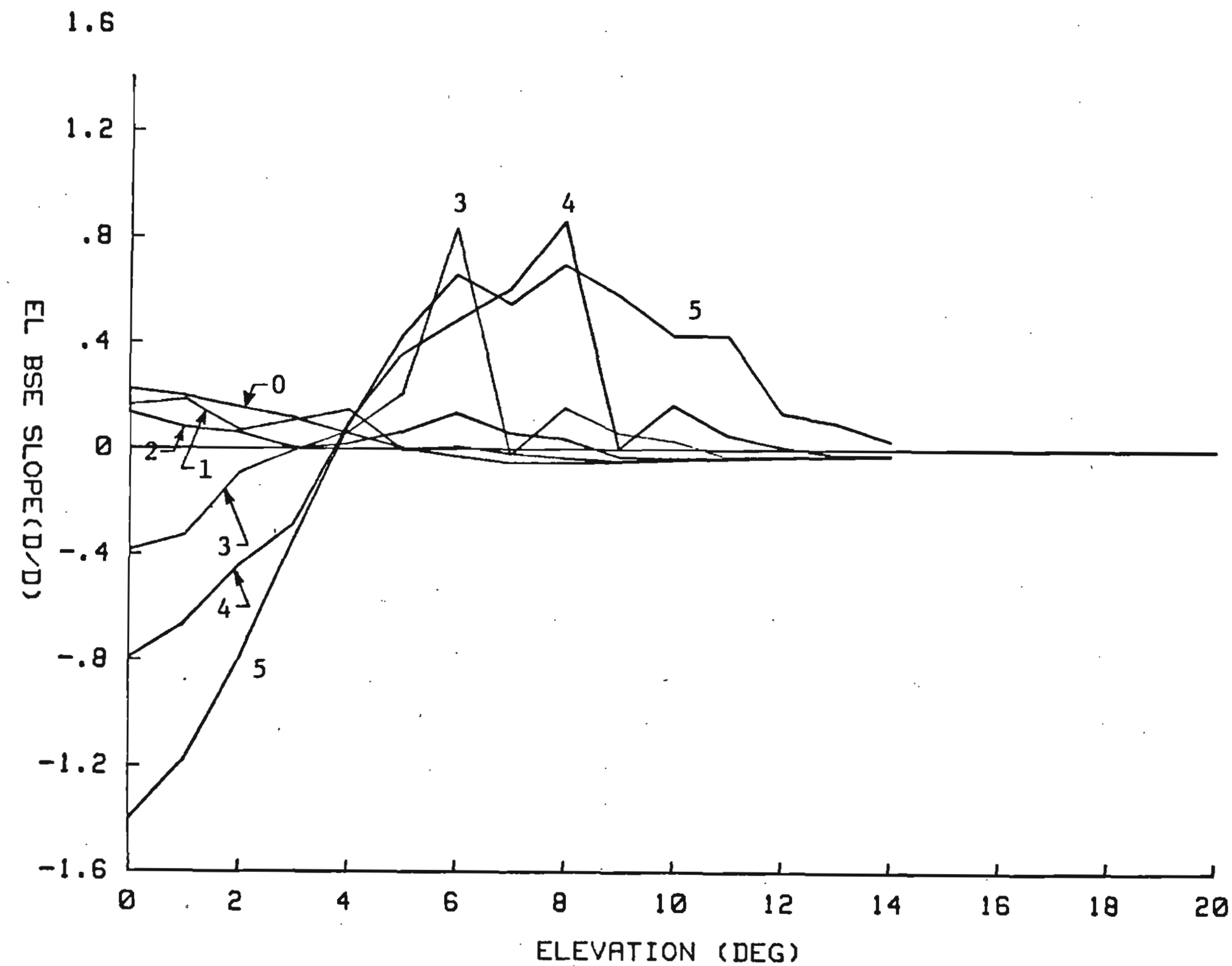


Figure 3.9. Elevation BSE slope as a function of elevation angle for apertures of 0 to 5 inches in diameter.

be target dependent for a resolved target since different areas of the target would appear to be blocked off from different areas on the antenna.

4.0 Mechanical Constraints on IR Seeker Size Reduction

The Hawk missile was fitted with an infrared seeker mounting plate. This seeker plate was mounted in the radome on a gimbal and was to track parallel to the IHAWK's antenna. The seeker plate utilized 4 strings that ran parallel to one another from the antenna to the seeker plate. The 4 string system proved viable mechanically, but the seeker assembly blocked too much of the radiation going to the RF antenna. This made the RF seeker unstable when tracking straight ahead.

The amount of radiation blockage can be reduced while keeping basically the same seeker and reel assembly designs. It has been determined that a reduction in blockage could be best done by decreasing the size of the seeker assembly (see Figure 4.10). This results in a two fold reduction in blockage. First, the actual blockage area, directly in front of the antenna, is reduced; secondly, the smaller seeker can be moved further from the RF antenna. This increase in distance will also reduce the angle the antenna must move to look around the seeker assembly.

The present diameter of the IR seeker assembly (Figure 4.12) was made as small as the hole pattern for the strings would allow. Therefore, a reduction in the displacement of the holes through the RF antenna would allow the use of a smaller IR seeker. The two waveguides across the back of the RF antenna fixed the largest dimension of this pattern (see Figure 4.10). The only way to reduce this dimension is to drill these holes between the waveguides on the back of the antenna (see Figure 4.11). The strings would cross underneath the baseplate and possibly use the same string adjusters to route them to the reel (see Figure 4.13).

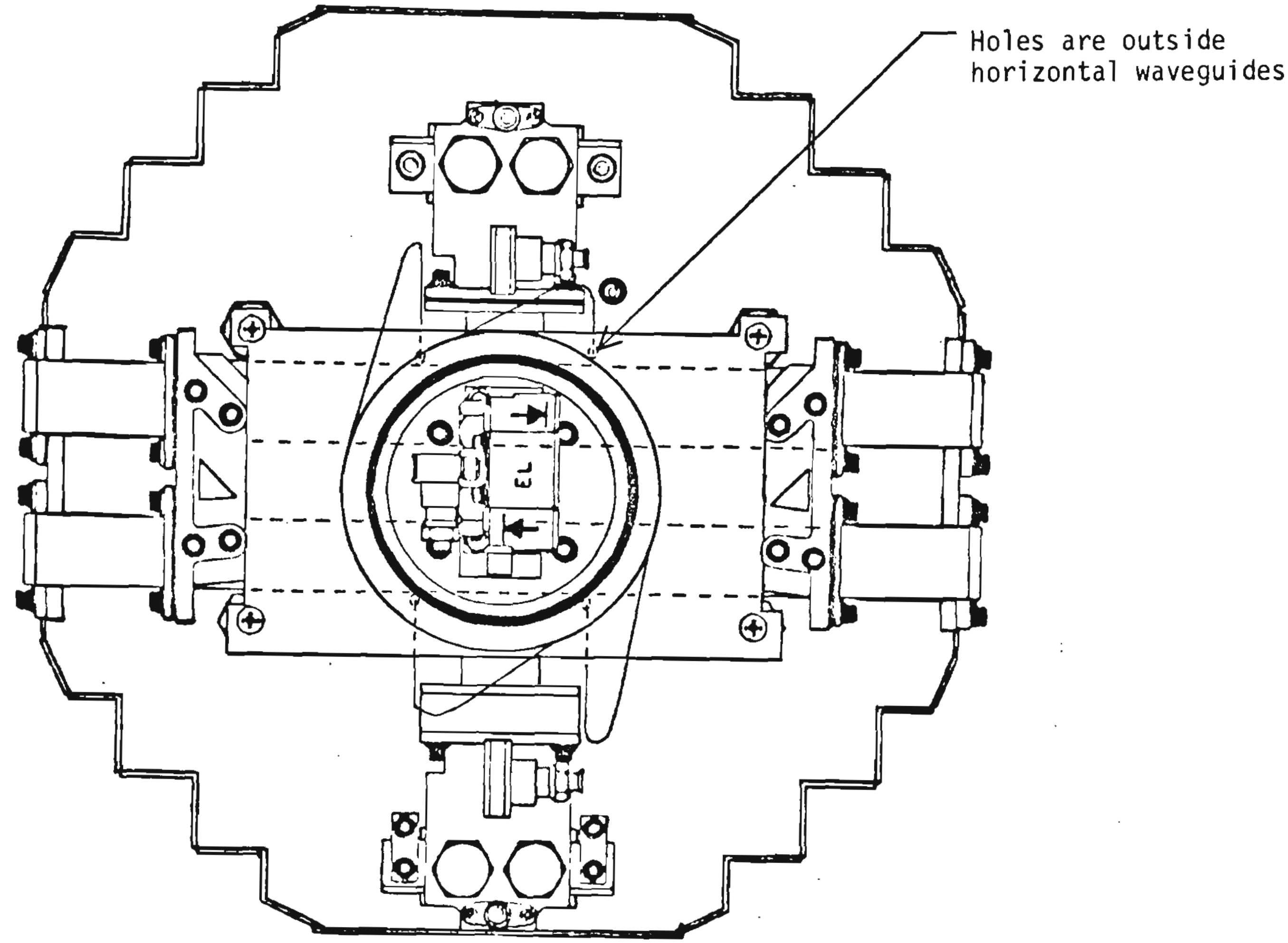


Figure 4.10. Present String Path

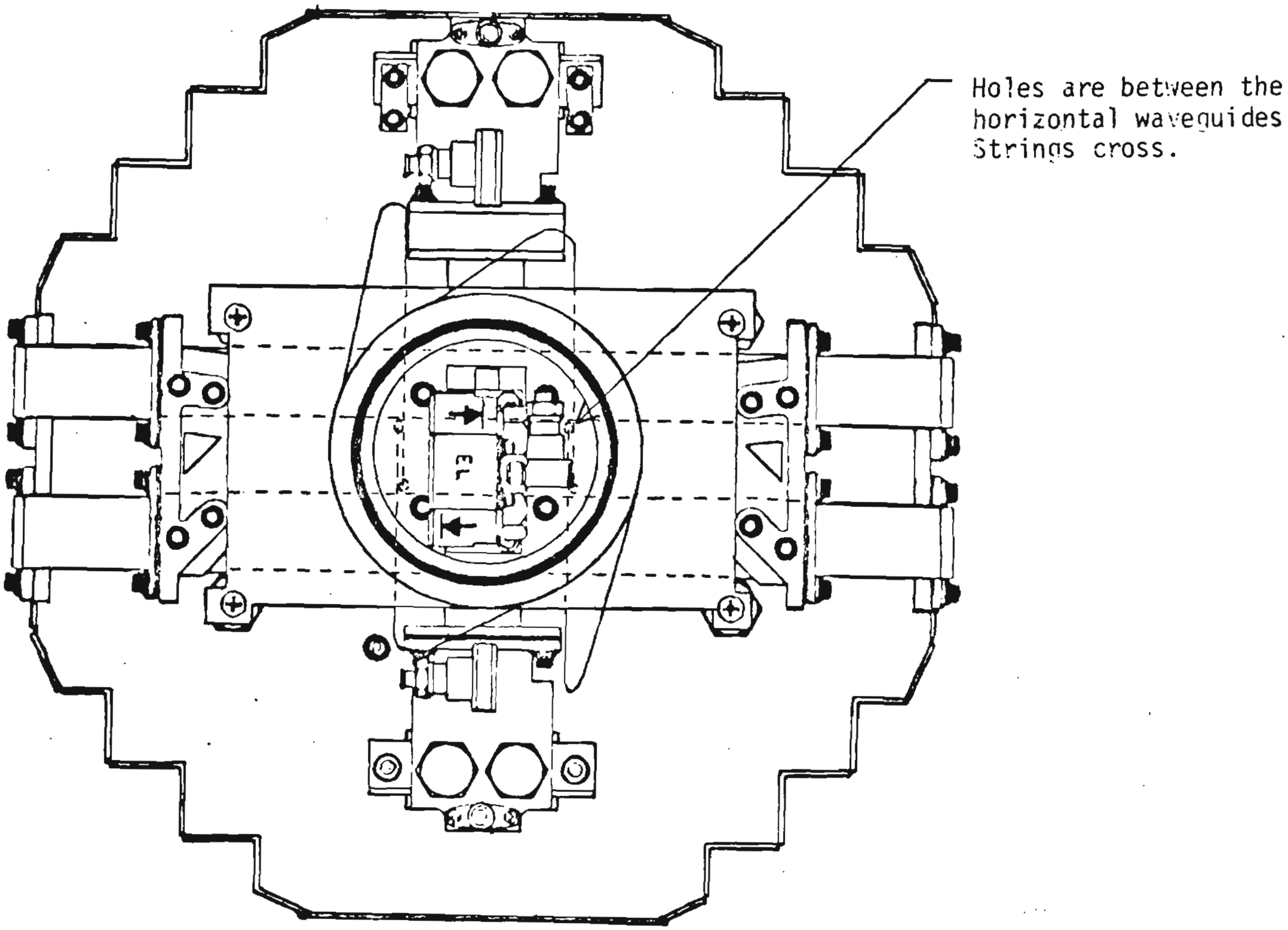


Figure 4.11. Proposed String Path.

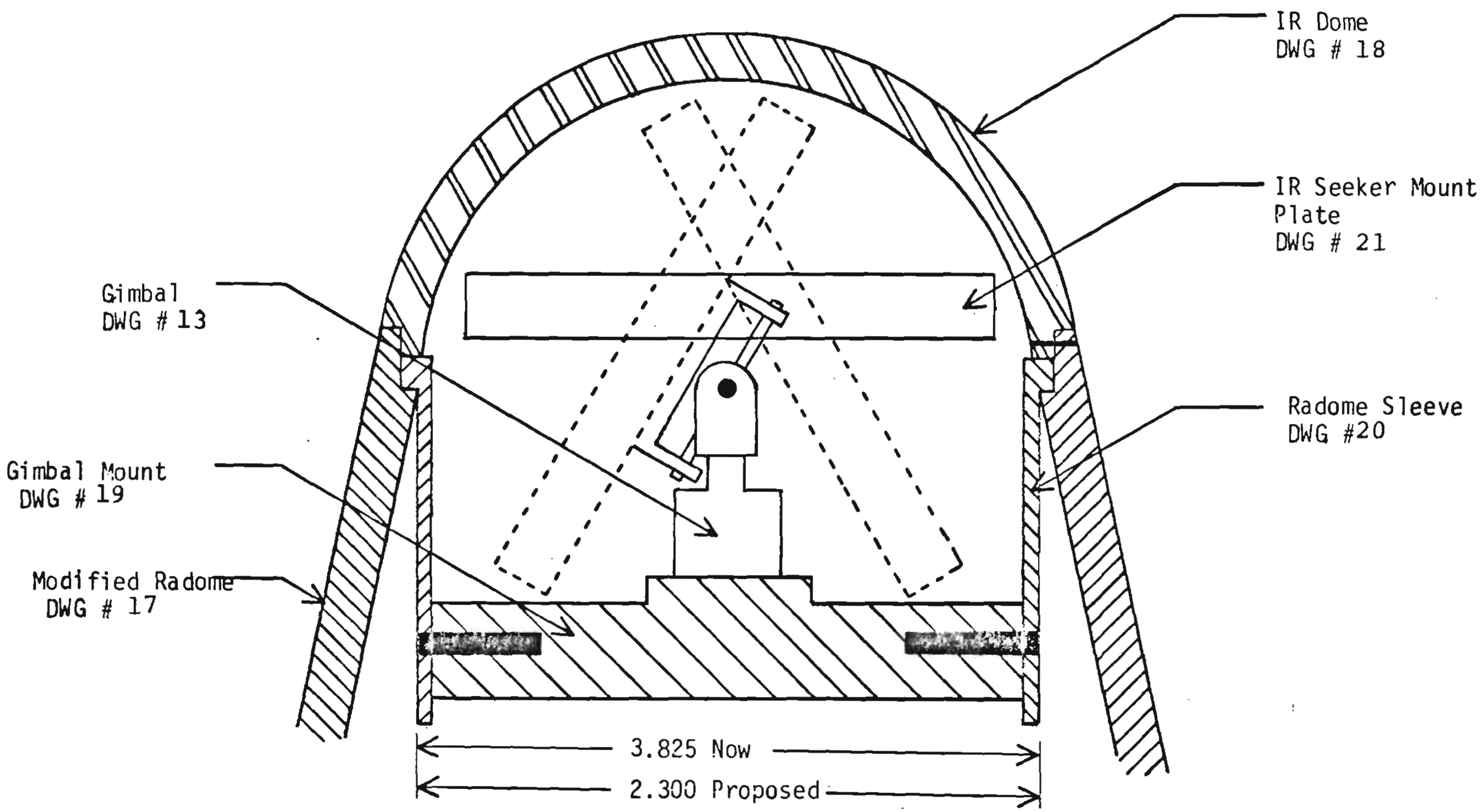


Figure 4.12. Infrared Seeker Assembly.

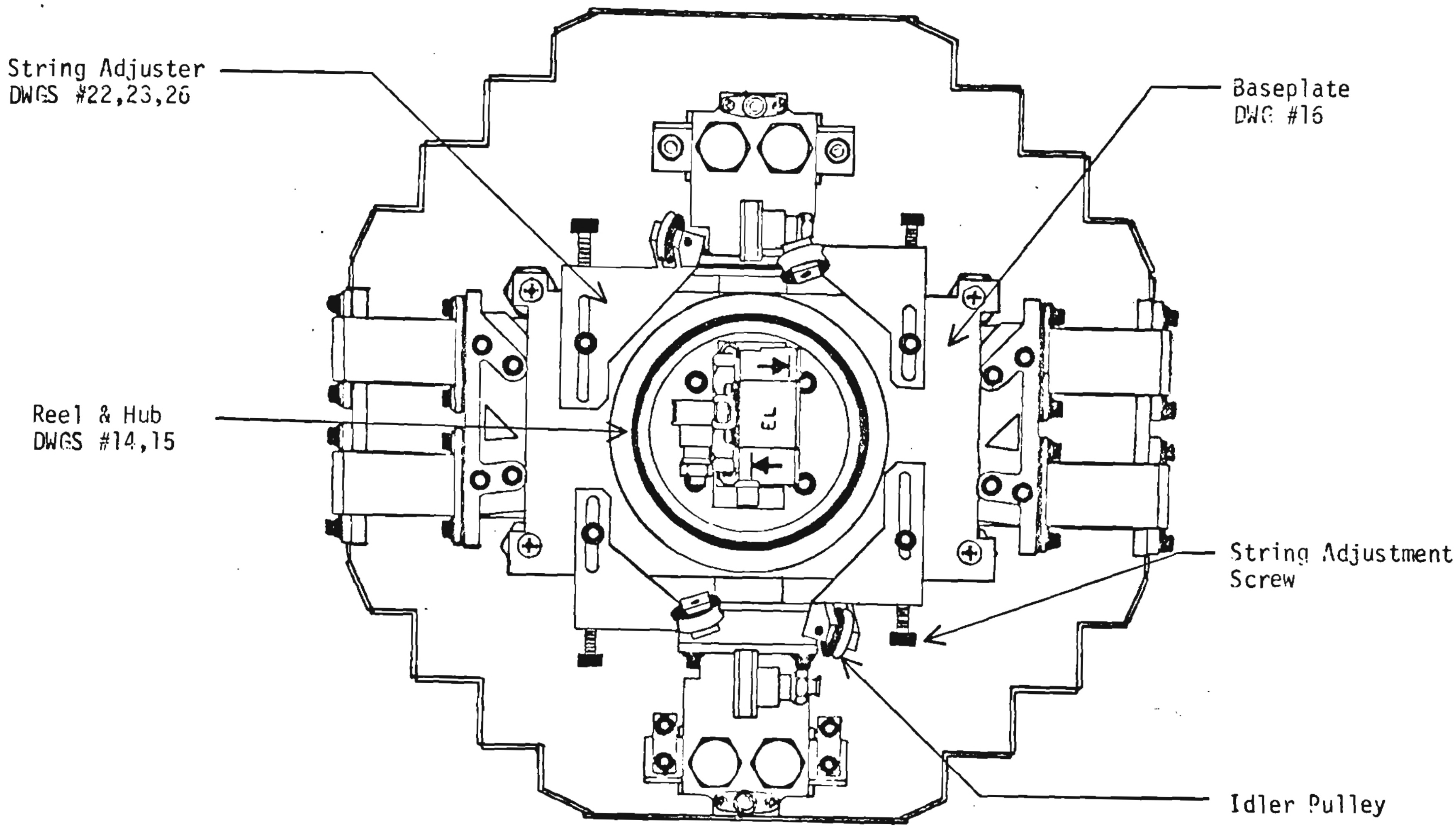


Figure 4.13. Present Reel Assembly.

The larger dimension of the hole pattern is the one where the holes are drilled between adjacent waveguide walls. This dimension cannot change without breaking through waveguide. Therefore, this dimension, 1.725 inches, Dwg. #25, controls the diameter of the seeker assembly. The IR seeker mount plate can now decrease in diameter and thickness. With the smaller mounting plate, the radome sleeve diameter can now be reduced to 2.3 inches (Figure 4.12).

The smaller IR seeker mounting plate requires 0.70 inches less space to rotate the required 55 degrees. The IR seeker mounting plate can be 0.125 inches thinner and the gimbal mounting can be 0.1 inches thinner. Therefore, the seeker assembly will be a total of 0.92 inches shorter.

The smaller seeker assembly diameter allows it to mount 3.52 inches forward of the present assembly in the radome. The shorter assembly and the move forward makes the distance from antenna to obstruction a total of 4.44 inches further than the present system. See Table 5.1 for calculations.

TABLE 4.1. CALCULATIONS (SEEKER SIZE REDUCTION)

1.725	+	2(0.032)	=	1.789
holes between waveguide walls		hole clearance		IR seeker mount plate dia.

3.115	-	1.789	=	1.326
existing mount plate				difference

2.10	+	0.100	=	2.300	(proposed
allowing for 1/4" thick IR seeker mount plate clearance for rotation		sleeve		sleeve body	seeker assembly O.D.= 2.300)

3.825	-	2.300	=	1.525
existing sleeve body		proposed sleeve body		diameter difference

0.700 on rotation	+	0.1	+	0.125	=	0.925 inches
shorten sleeve due to smaller seeker dia.		thickness change of gimbal mount		thinner IR seeker mount plate		total IR seeker assembly length change

x is the distance seeker assembly moves forward

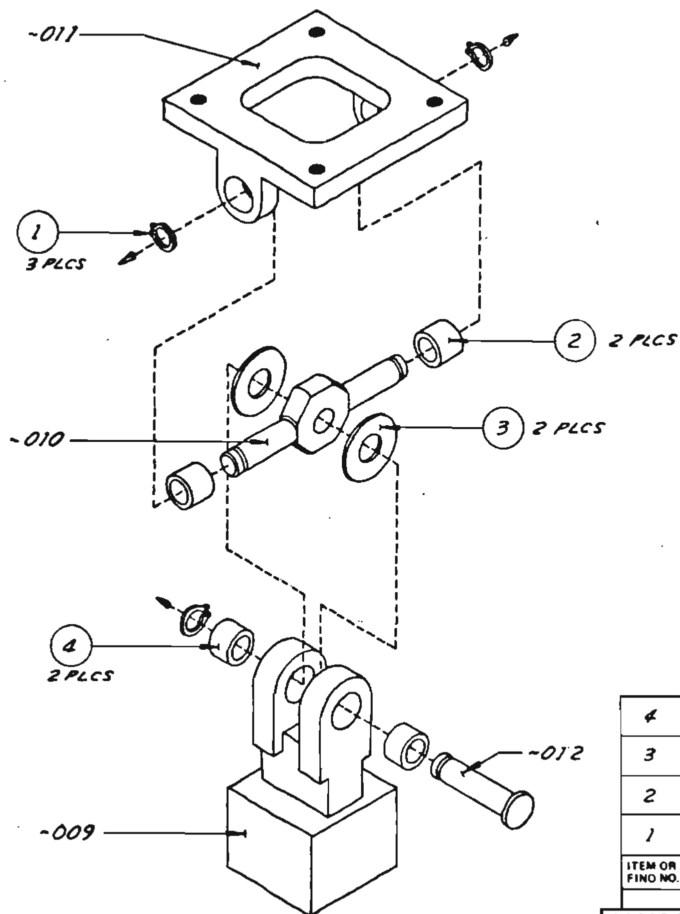
12.5^{o} is approximate radome angle

x sin 12.5^{o} = 1.525/2   x = 1.525/25 in 12.5^{o}= 3.52

+0.92

4.44 - actual dist. assembly is moved

APPENDIX



APPLICATION			REVISIONS				
QTY REQD	NEXT ASSY	USED ON	ZONE	SYM	DESCRIPTION	DATE	APPROVED
1	FINAL						

PARTS LIST

ITEM OR FIND NO.	QTY REQD		NOMENCLATURE OR DESCRIPTION	MATL SPEC AND SIZE OR COMPONENT VALUE	IDENTIFYING OR PART NO.	CODE IDENT.
4	2		'OILITE' BRONZE	1/8 ID, 3/16 OD x 5/32 LONG		
3	2		'OILITE' BRONZE	1/4 ID, 3/8 OD x 1/32 THK.		
2	2		'OILITE' BRONZE	1/8 ID, 3/16 OD x 1/8 LONG		
1	3		SNAP RING	1/8" NOM. SHAFT		

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED

TOLERANCES
3 PLACE DECIMALS ±
2 PLACE DECIMALS ±
1 PLACE DECIMAL ±
FRACTIONS ± ANGLES ± 0°30'

MAX SURFACE ROUGHNESS 125 ALL MACHINED SURFACES EXCEPT AS NOTED

BREAK SHARP EDGES AND CORNERS .010 MAX

FINISH

CONTRACT NO A3447		
DWN WLM	3-16-83	
ENGR		
CHK		
PROD		
APVD		
APVD		

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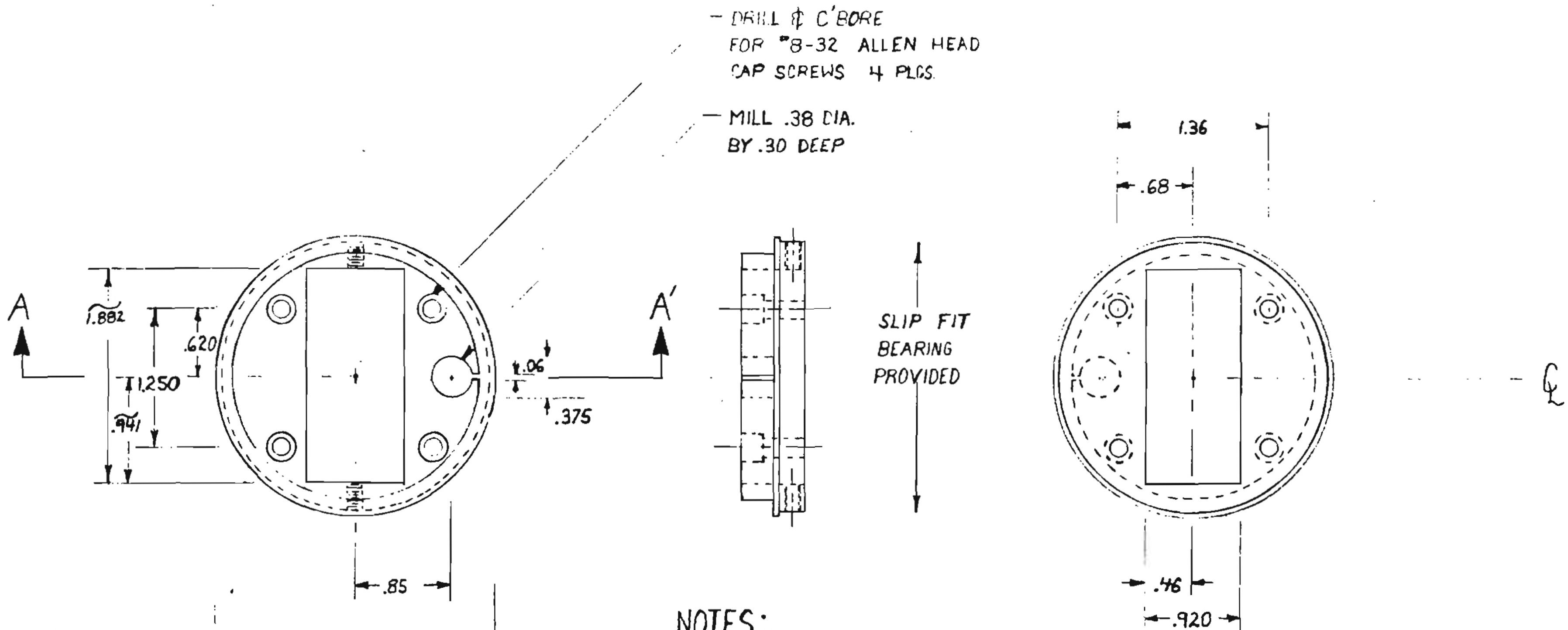
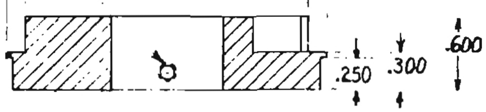
GIMBAL ASSEMBLY

SIZE	CODE IDENT NO.	DRAWING NO.	REV
C		A3447-013	
SCALE 2X		SHEET	

A3447-013





SECTION A~A'

NOTES:

1) MAT'L: ALUM. 6061-T6
2) MATCH DRILL #8-32 CLEARANCE HOLES WITH BASEPLATE DWG # 016
3) FINISH: BEADBLAST & IRRIDITE

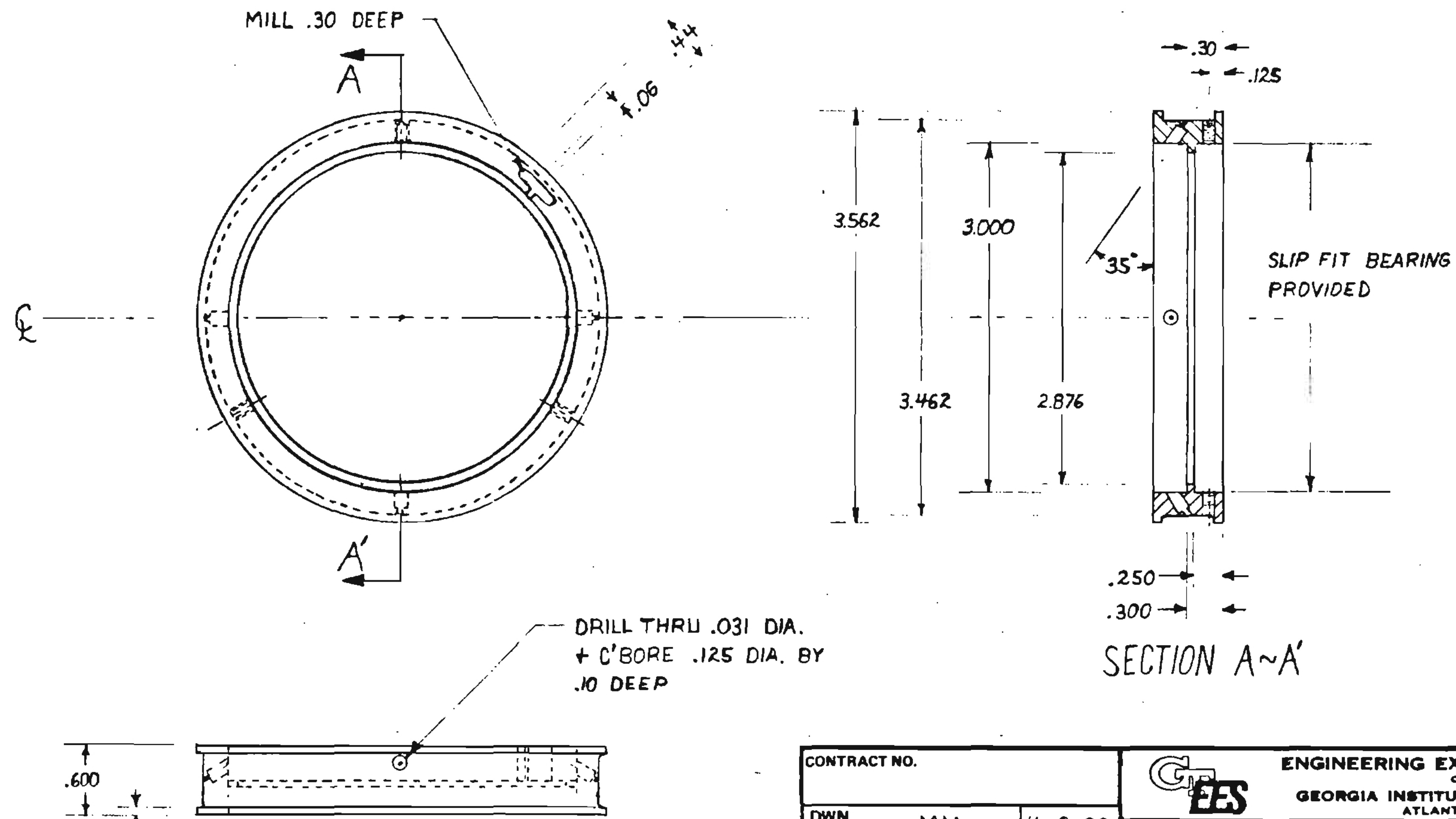
CONTRACT NO.		
DWN	MAL	4-6-83
ENGR		
CHK		
PROD		
APVD		
APVD		

ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

REEL HUB

SIZE	CODE IDENT NO.	DRAWING NO.
B		A-3447-014
SCALE FULL		SHEET

AF 26393A



NOTES:
1) MAT'L: ALUM. 6061-T6
2) FINISH: IRRIDITE
3) MAKE TIGHT SLIP FIT

CONTRACT NO.		
DWN	MAL	4-6-83
ENGR		
CHK		
PROD		
APVD		
APVD		

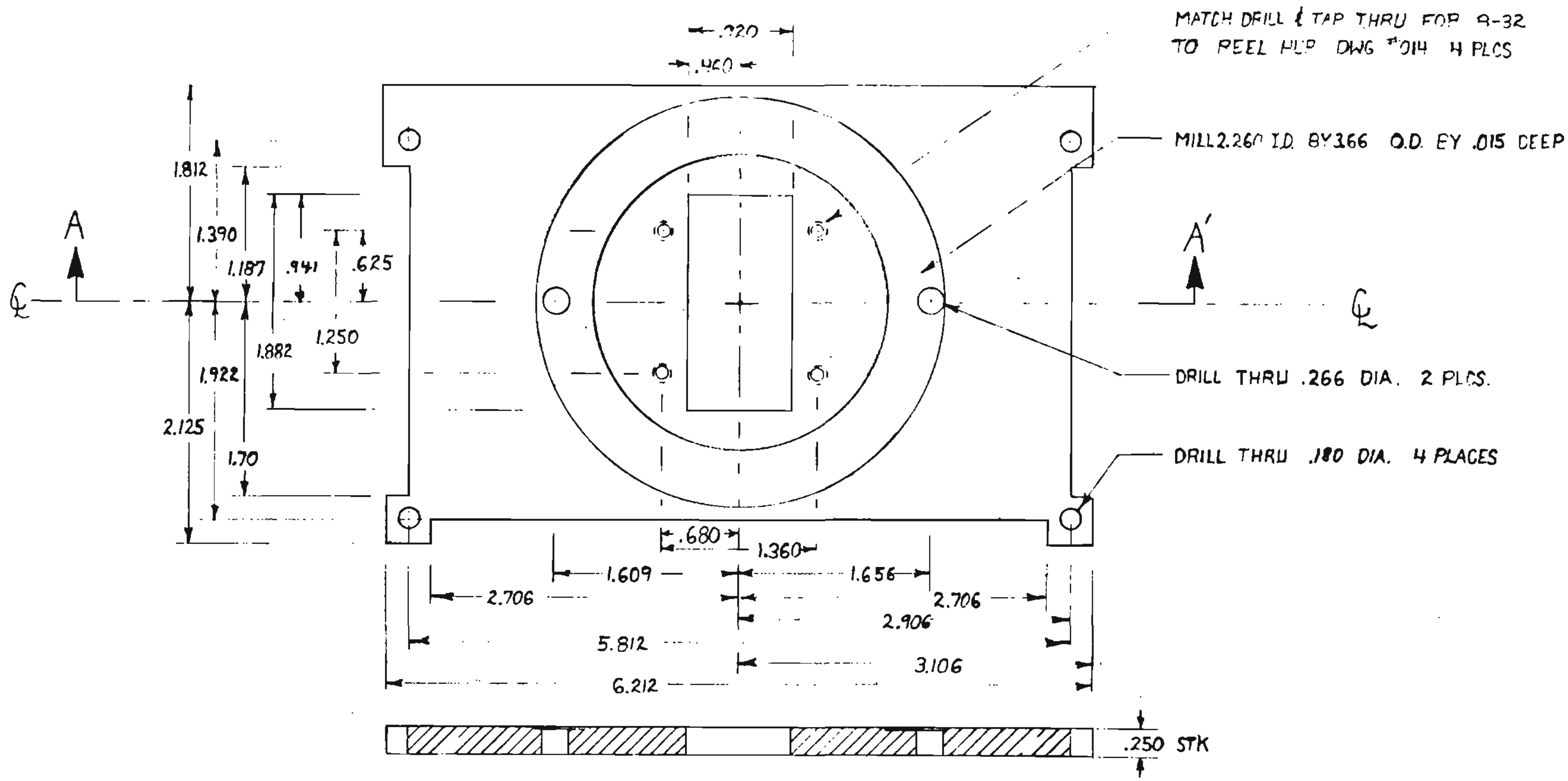
ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

REEL

SIZE	CODE IDENT NO.	DRAWING NO.
B		A-3447-015

SCALE: U1. SHEET

AF 26593A



SECTION A~A'

NOTES:
1) MAT'L ALUM. 6061-T6
2) TOLERANCES: .XXX ± .005
3) IRRIDITE

CONTRACT NO.		
DWN	MAL	4-8-63
ENGR		
CHK		
PROD		
APVD		
APVD		

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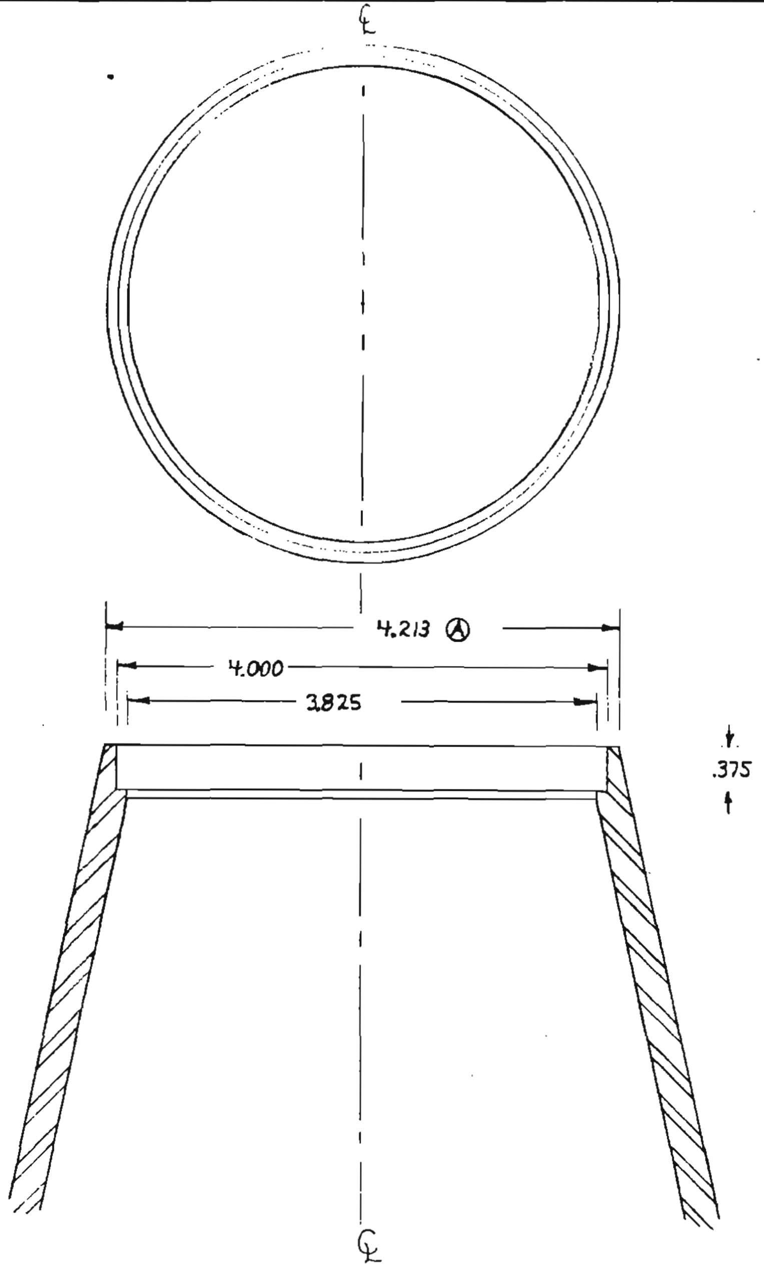
ATLANTA, GEORGIA

BASEPLATE

SIZE	CODE IDENT NO.	DRAWING NO.
B		A-3447-016
SCALE FULL		SHEET

AF 25593A

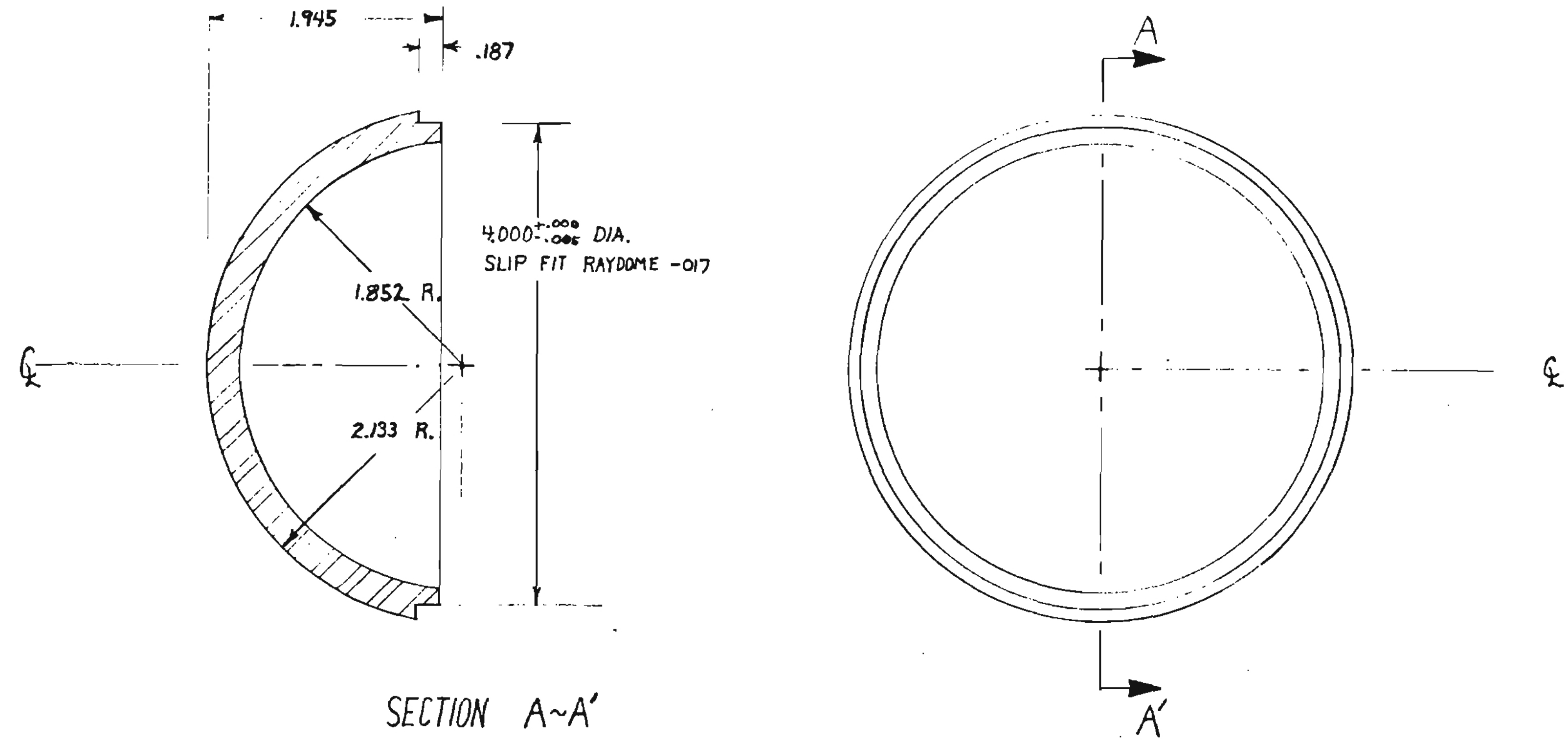


NOTES:

1) MAT'L RAYDOME PROVIDED
2) CUT OFF RAYDOME TILL DIA. REACHES DIMENSION Ⓐ

CONTRACT NO.		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA
DWN	MAL	4-14-83
ENGR		RADOME MODIFICATION
CHK		
PROD		
APVD		SIZE B · CODE IDENT NO. · DRAWING NO. A-3447-017
APVD		SCALE Full · SHEET

AP 26393A

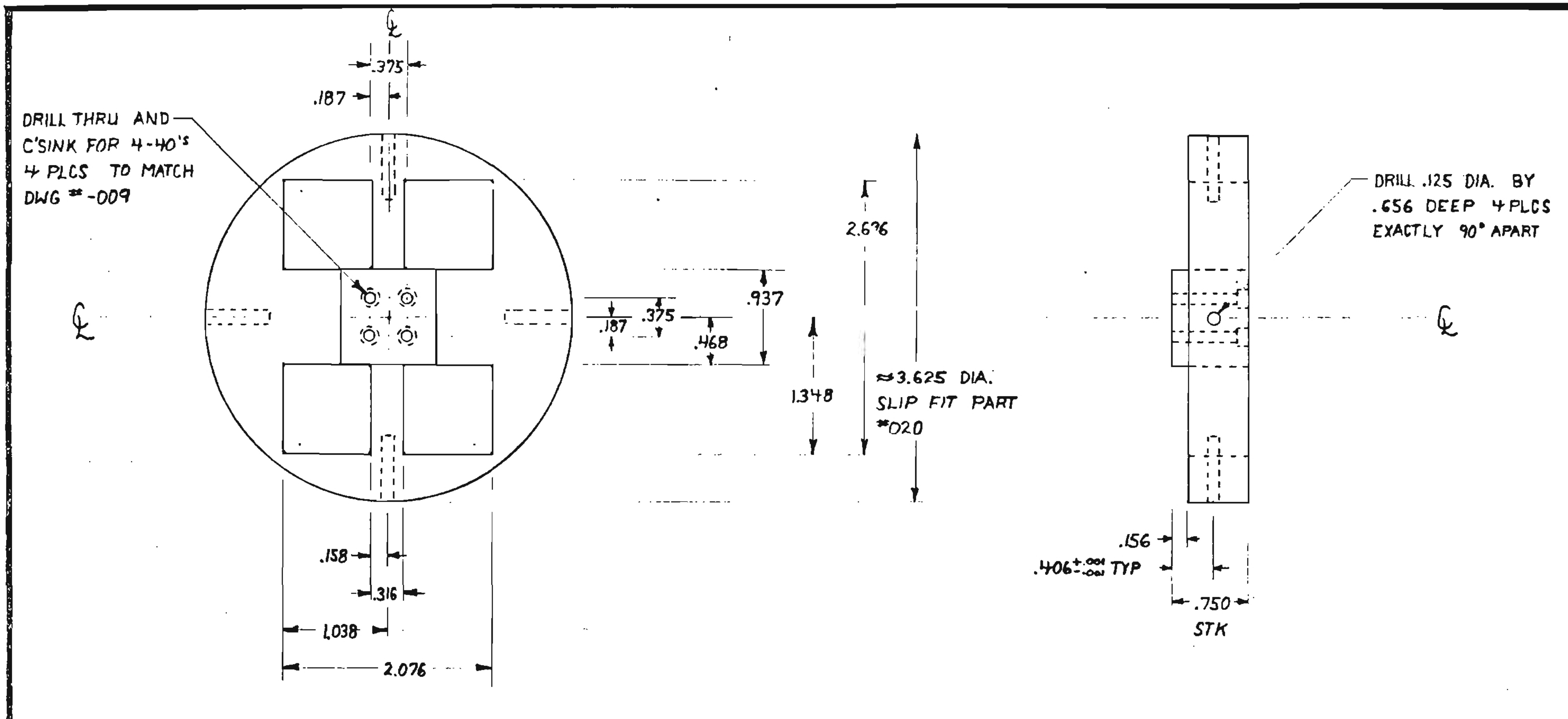


SECTION A~A′

NOTES:
1) MAT'L PLEXIGLAS
2) POLISH FINISH

CONTRACT NO.			ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA
DWN	MAL	4-15-83	IRDOME
ENGR			
CHK			
PROD			
APVD			SIZE B · CODE IDENT NO. · DRAWING NO. A-3447-018
APVD			SCALE FULL · SHEET

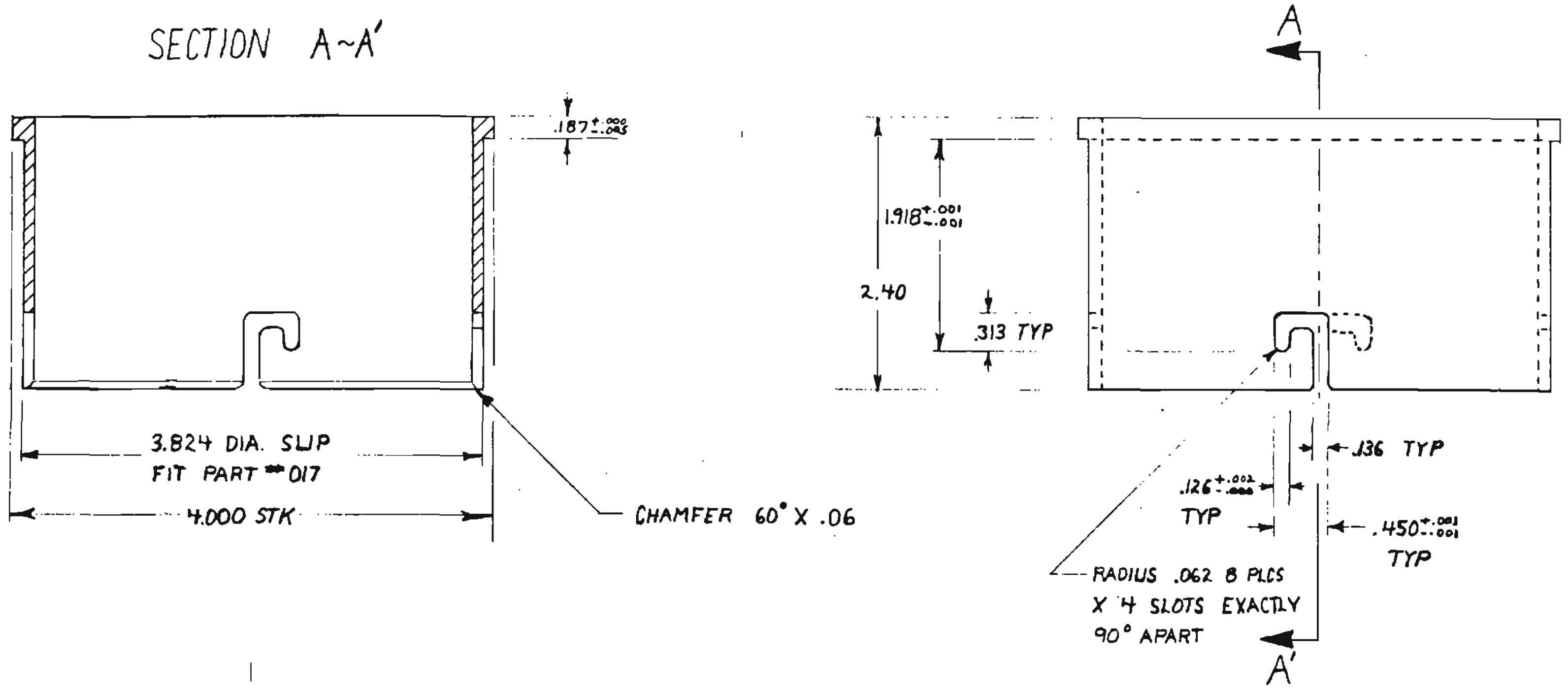
AF 26393A

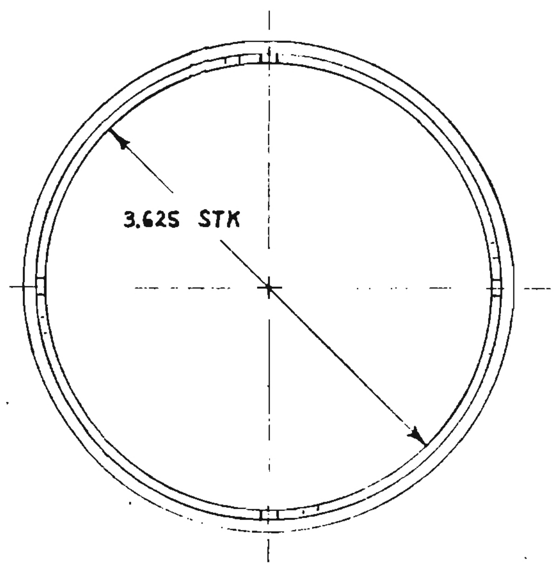


NOTES:

1) MAT'L G-10 FIBERGLASS
2) TOLERANCES: .XXX ± .005 EXCEPT AS NOTED

CONTRACT NO.		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA
DWN MAL	4-19-83	
ENGR		GIMBAL MOUNT
CHK		
PROD		
APVD		SIZE B — CODE IDENT NO. — DRAWING NO. A-3447-019
APVD		SCALE FULL — SHEET



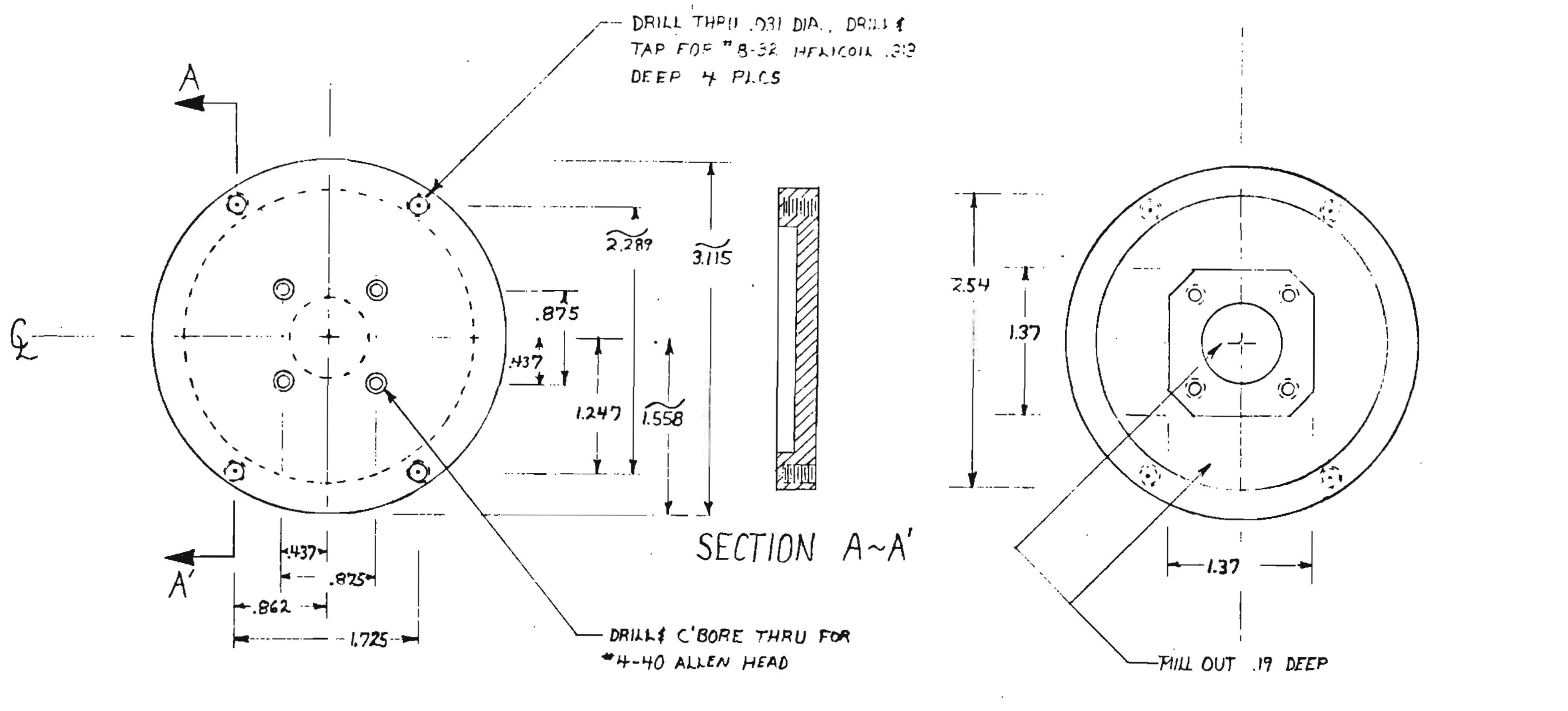


NOTE:
1) MAT'L 4"O.D. BY 3/16 WALL G-10 FIBERGLASS TUBE
2) SLOTS ARE SUCH THAT PART # 019 TURNS CLOCKWISE TO LOCK

TOLERANCES:
.XXX ± .005
EXCEPT AS NOTED

CONTRACT NO. A-3447		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA			
DWN MAL	4-20-83	RADOME SLEEVE			
ENGR					
CHK					
PROD					
APVD		SIZE B	CODE IDENT NO.	DRAWING NO. A-3447-020	
APVD		SCALE			SHEET

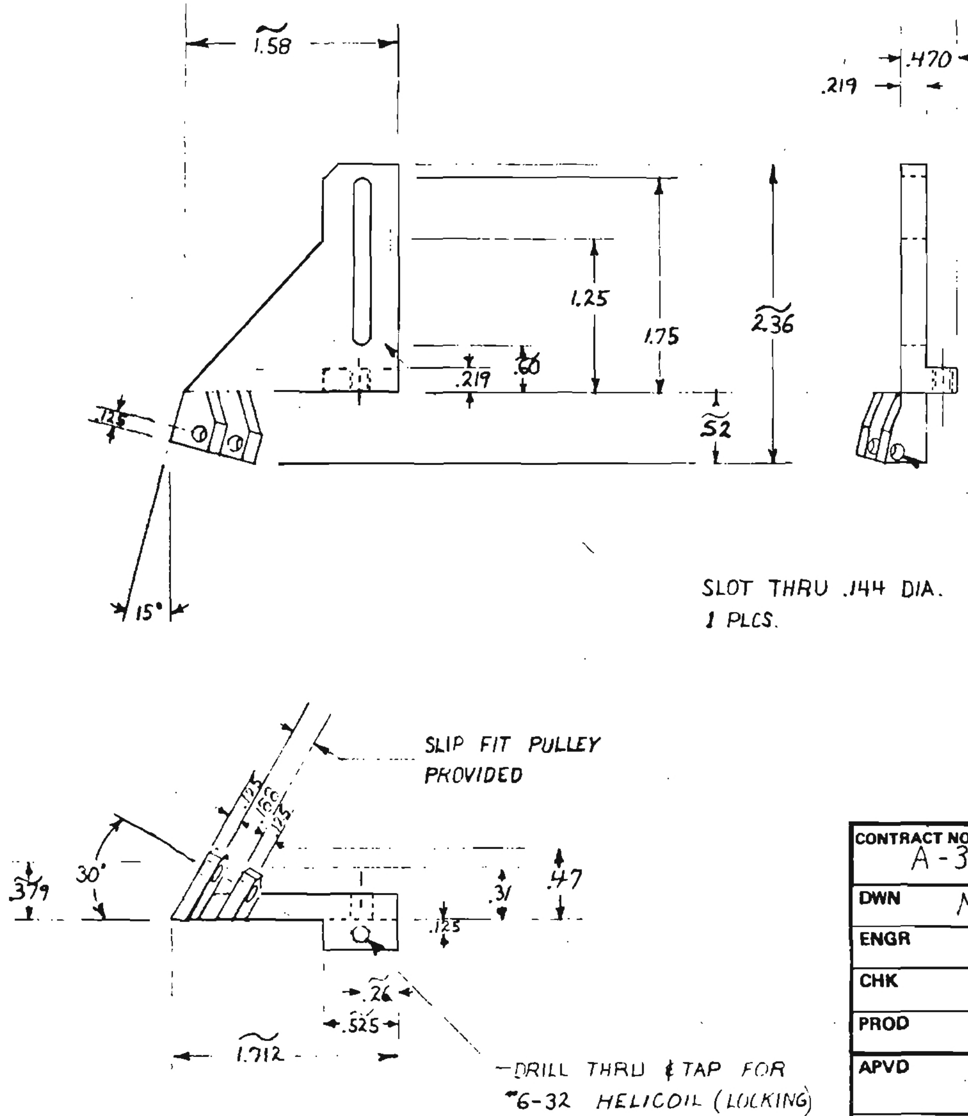
AF 26393A



NOTES:

1) MAT'L 3/8" STK G-10 FIBERGLASS
2) TOLERANCES: .XXX ±.005

CONTRACT NO. A-3447-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA		
DWN MAL	4-22-83	IR SEEKER MOUNT PLATE		
ENGR				
CHK				
PROD				
APVD		SIZE B	CODE IDENT NO.	DRAWING NO. A-3447-021
APVD		SCALE FULL		SHEET



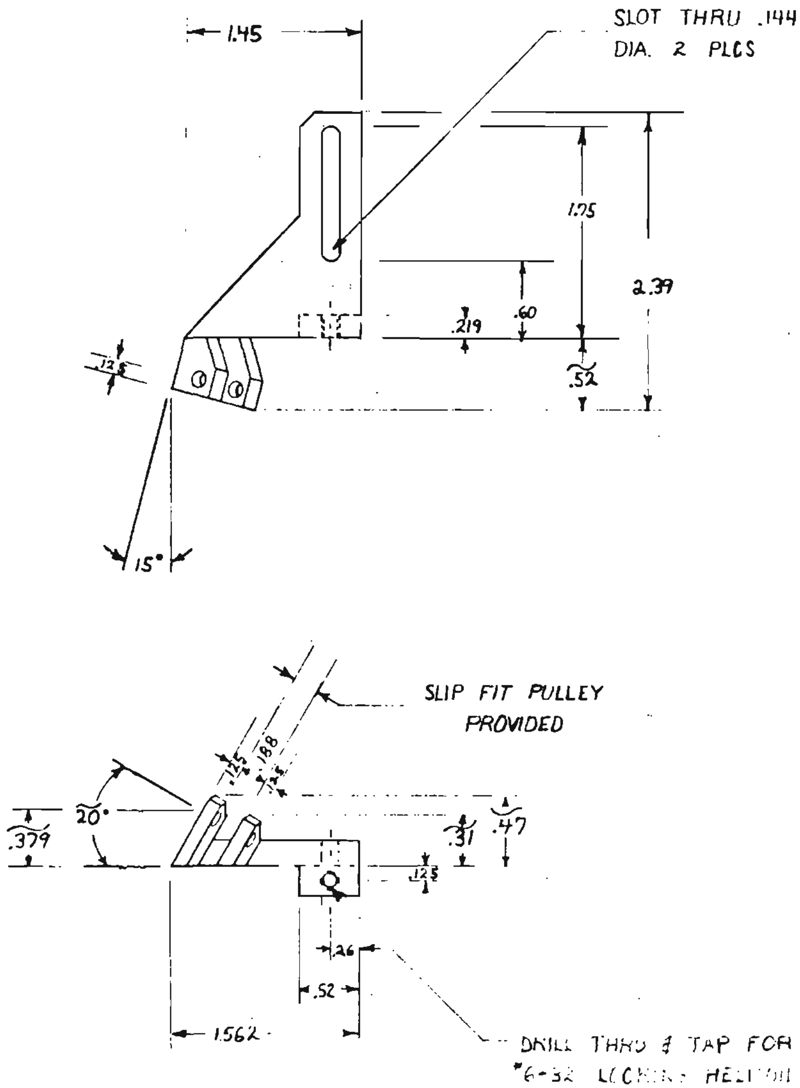
DRILL THRU .125
DIA. SLIP FIT PIN

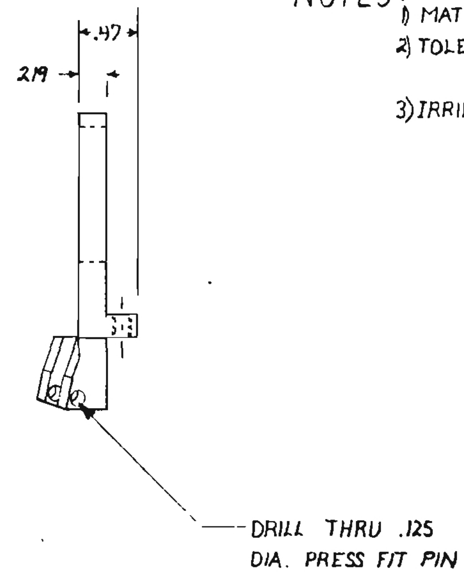
NOTES:

1) MAT'L ALUM. 6061-T6
2) TOLERANCES: .XXX ± .005
.XX ± .01

CONTRACT NO. A-3532-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA	
DWN MAL	5-10-83	SUM RT. STRING ADJUST	
ENGR			
CHK			
PROD			
APVD		SIZE B	CODE IDENT NO.
APVD		SCALE FULL	DRAWING NO. A-3147-[illegible]2
			SHEET

AF 26393A

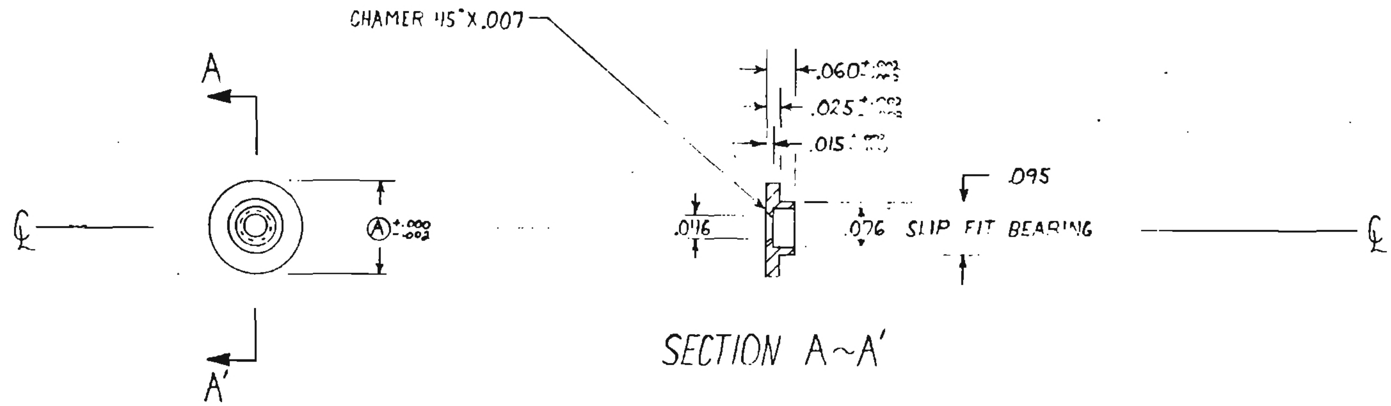




NOTES:
1) MAT'L ALUM. 6061-T6
2) TOLERANCES : .XXX ± .005
.XX ± .01
3) IRRIDITE

CONTRACT NO. A-3532-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA
DWN MAL	5-11-83	AZ. LT. STRING ADJUST
ENGR		
CHK		
PROD		
APVD		SIZE B · CODE IDENT NO. · DRAWING NO. A-3447-023
APVD		SCALE · SHEET

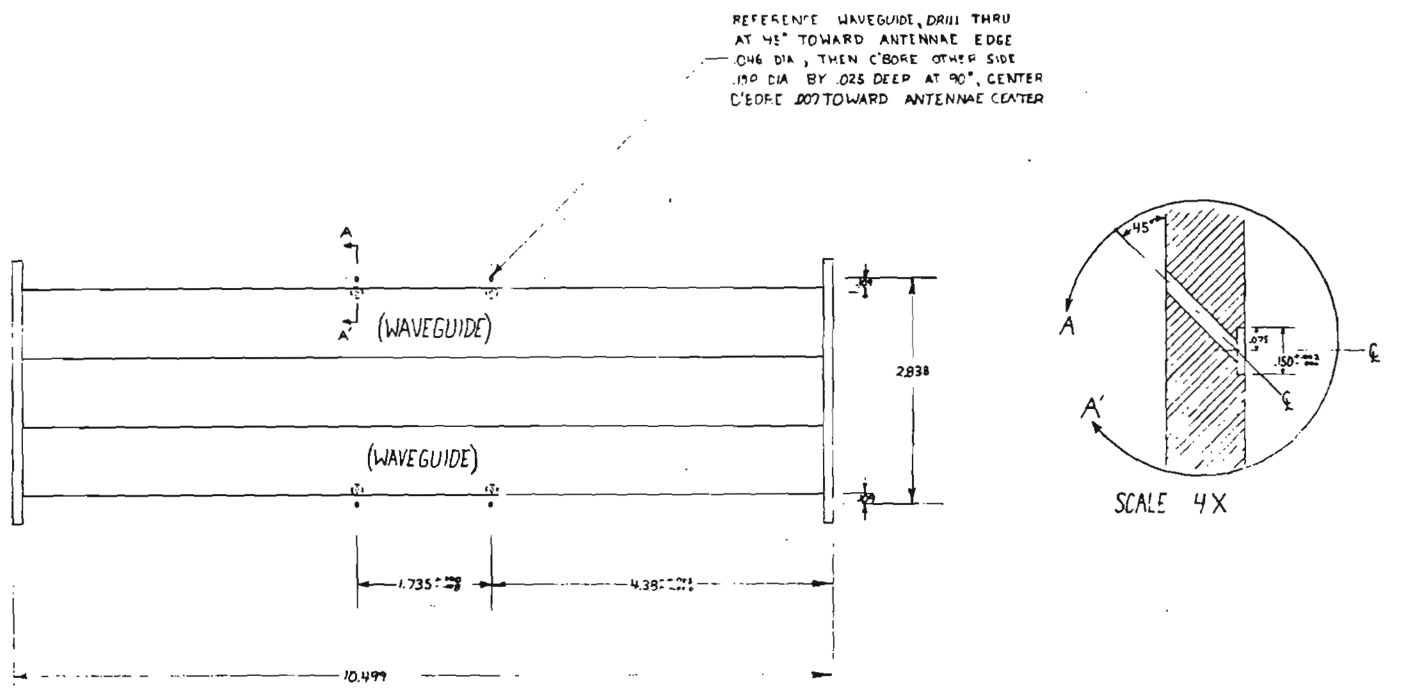
AF 26393A



NOTES:

1) MAT'L ALUM.
2) DIMENSIONS Ⓐ .192 , .193 , .195 , .196
3) TOLERANCES: .XXY ± .005 EXCEPT AS NOTED
4) IRRIDITE FINISH

CONTRACT NO. A-3532-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA		
DWN MAL	5-23-83	BEARING CUP		
ENGR				
CHK				
PROD				
APVD		SIZE B	CODE IDENT NO.	DRAWING NO. A-3447-024
APVD		SCALE 10X		SHEET



APPLICATION		
QTY REQD	NEXT ASSY	USED ON

REVISIONS				
ZONE	SYM	DESCRIPTION	DATE	APPROVED

PARTS LIST

ITEM OR FIND NO.	QTY REQD	NOMENCLATURE OR DESCRIPTION	MATL SPEC AND SIZE OR COMPONENT VALUE	IDENTIFYING OR PART NO.	CODE IDENT.

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED
TOLERANCES
3 PLACE DECIMALS ± .005
2 PLACE DECIMALS ±
1 PLACE DECIMAL ±
EXCEPT AS NOTED
FRACTIONS ± ANGLES ± 0°30'
MAX SURFACE ROUGHNESS 125 ALL MACHINED SURFACES EXCEPT AS NOTED
BREAK SHARP EDGES AND CORNERS .010 MAX
FINISH

CONTRACT NO.		
DWN	MAL	5-17-83
ENGR		
CHK		
PROD		
APVD		
APVD		

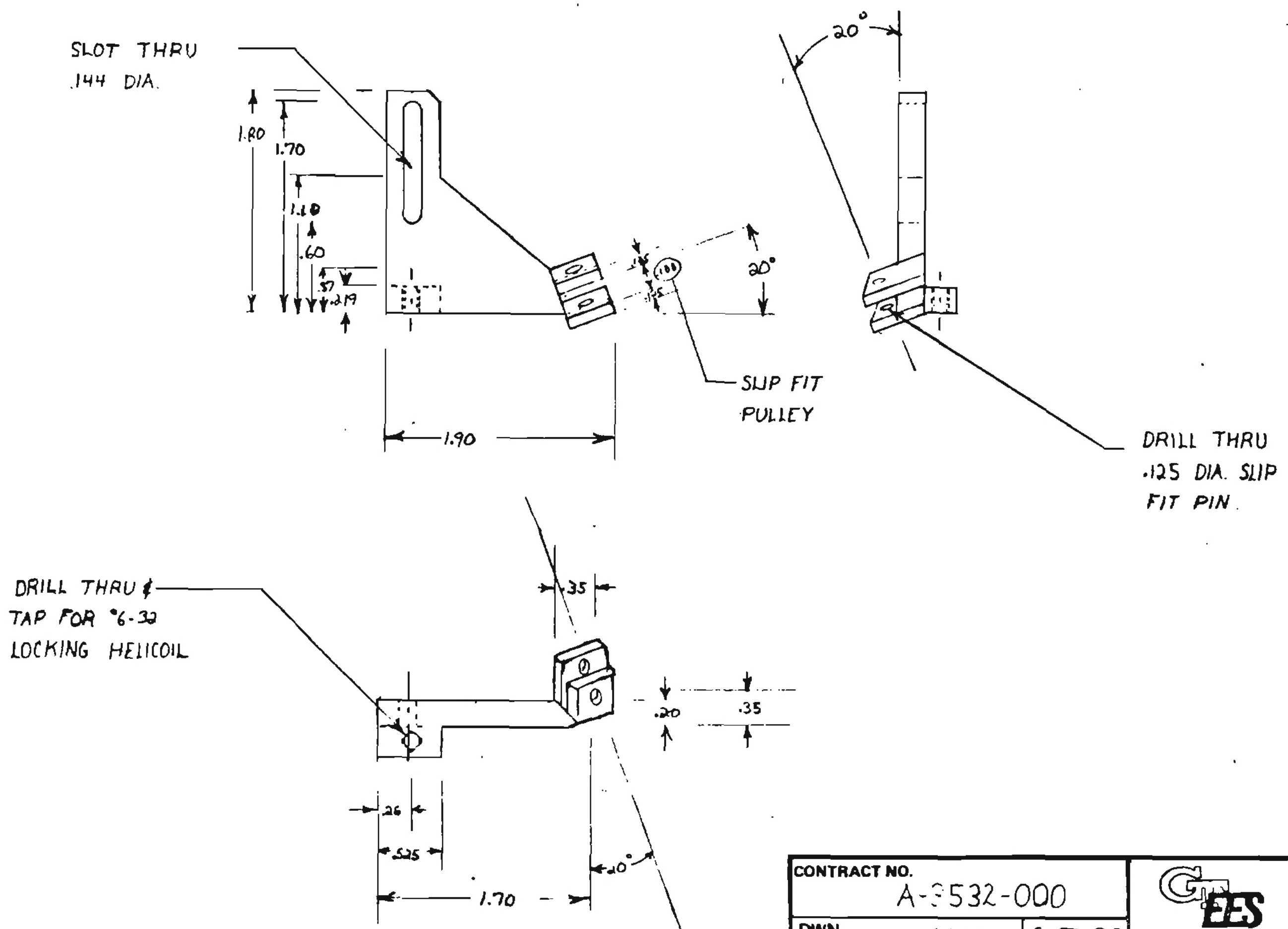
GTEES ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA

ANTENNAE MODIFICATION

SIZE	CODE IDENT NO.	DRAWING NO.	REV
C		A-3447-025	

SCALE FULL EXCEPT AS NOTED SHEET

AF 26393A



NOTES:
1) MAT'L ALUM. 6061-T6
2) TOLERANCES .XXX ± .005
.XX ± .010
3) ROUND CORNERS
4) IRRIDITE FINISH

CONTRACT NO. A-3532-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA
DWN MAL	6-7-83	SUM LT. STRING ADJUST
ENGR		
CHK		
PROD		
APVD		SIZE B; CODE IDENT NO.; DRAWING NO. A-3447-026
APVD		SCALE FULL; SHEET

AF 26383A

NOTES:
1) MAT'L TEFLON
2) TOLERANCES : .XXX ± .005
EXCEPT AS NOTED .XX ± .010

CONTRACT NO.		
DWN	MAL	6-7-83
ENGR		
CHK		
PROD		
APVD		
APVD		

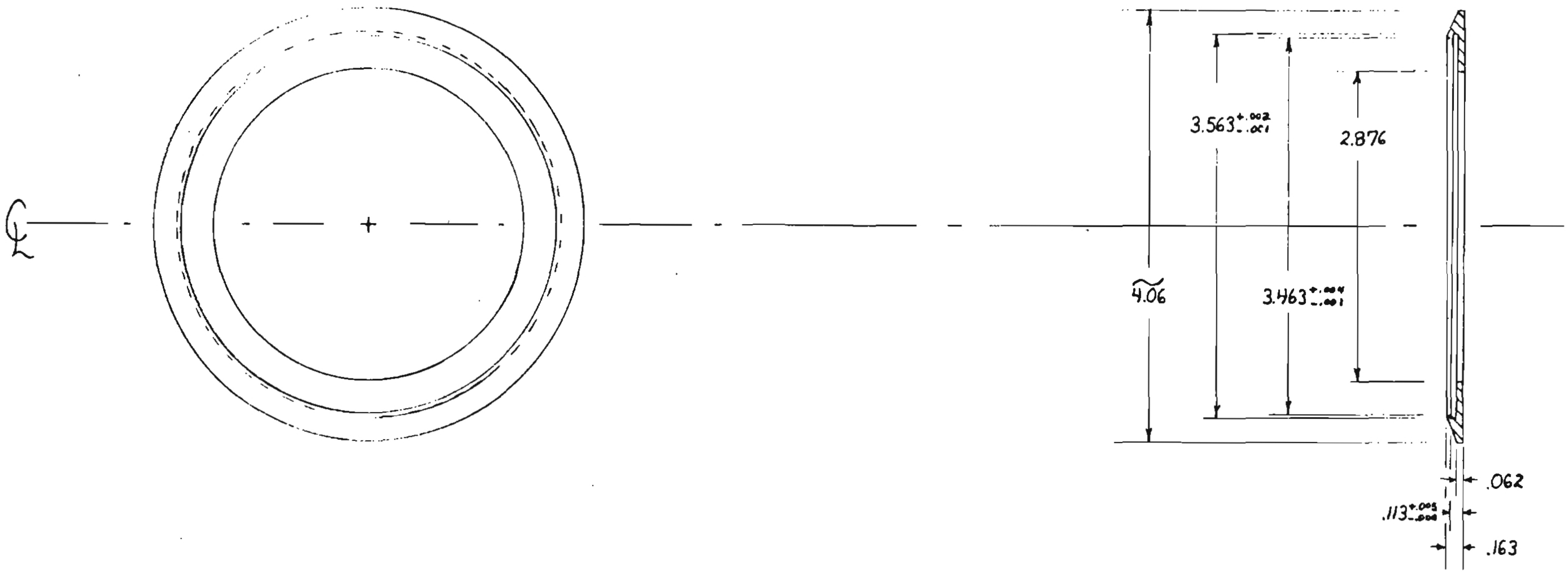
GT EES
ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

STRING GUIDE

SIZE	CODE IDENT NO.	DRAWING NO.
B		A-3447-027

SCALE		SHEET
2X		

AF 26393A



NOTES:

1) MAT'L POLYETHELENE
2) TOLERANCES: .XXX ± .005
EXCEPT AS NOTED .XX ± .010

CONTRACT NO. A-3532-000		ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA		
DWN MAL	6-16-83	REEL CUP		
ENGR				
CHK				
PROD				
APVD		SIZE B	CODE IDENT NO.	DRAWING NO. A-3447-028
APVD		SCALE FULL		SHEET